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⑫ Plantation management
⑬ Coconut Palm planting.

Coconut palms in India

(2)

THE
COCONUT PALM
A MONOGRAPH

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By

K. P. V. MENON, B.Sc. [illegible]
Director
Central Coconut Research Station, Kay[illegible]gulam

and

K. M. PANDALAI, M.Sc., Ph.D., F.R.I.C.
Joint Director
Central Coconut Research Station, Kasaragod.

INDIAN CENTRAL COCONUT COMMITTEE
ERNAKULAM — S. INDIA
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Coconut palm: Mo..

Published by Dr. P. J. Gregory, the Secretary at Ernakulam for the Indian Central Coconut Committee, and printed by Pyarelal Sah at the Times of India Press, Bombay, India.

FOREWORD

THE coconut palm which for many centuries past has had the distinction of being styled *Kalpa Vriksha* (Tree of Heaven) still continues to dominate the tropical scene. In the areas where it is grown, the economic well-being of the bulk of the population depends on this multi-purpose palm. Every part of it is used for some essential purpose or other. The trunk of the mature tree is used for constructing houses, the leaves are plaited to thatch roofs and the inflorescences or unopened spadices are tapped to extract a juice which is converted into jaggery, sugar, vinegar and sweet or fermented toddy. It is, however, the nut it bears, that forms the most important part of the tree. The outer husk of the nut is retted and upon the fibre extracted from it is built the great coir industry, one of India's foreign exchange earners. The shell is used as fuel and when subjected to destructive distillation and other necessary processes, yields activated charcoal, acetic acid and a tarry residue. The shell lends itself as a medium for the expression of the finest instincts of the craftsmen of the East. Shell art-ware with their exquisite carvings and finish are much sought after by collectors of curios. Next to the shell comes the kernel, the most important part of the nut. The fresh kernel which is very sweet to the taste indeed, is consumed as such in considerable quantities in the areas where the palm is grown. In the Kerala State where nearly 70 per cent of the Indian coconut area is concentrated, the coconut kernel is the *sine qua non* of the dietary of the people and is their principal source of fat. The kernel on being dried, either in the sun or in kilns, is crushed for the oil it contains. The oil is used both for edible and industrial purposes. It is an indispensable ingredient in the manufacture of soap. It is no wonder that a tree with such a diversity of uses has been called in India with characteristic oriental imagination, *Kalpa Vriksha* or the Tree of Heaven.

India has 15·87 lakhs of acres under coconut and produces about 415 crores of nuts per annum. About 70 per cent of the area is, as already mentioned, situated in Kerala, about 14 per cent in Mysore and the remainder in the States of Madras, Bombay, Orissa, Andhra, West Bengal, Assam, the Andamans and the Laccadives. It is, however, a well-known fact that India is not producing enough coconuts for her requirements and therefore has to import coconuts and coconut products from countries like Ceylon, Malaya, etc., in considerable quantities.

For a long time the Indian coconut industry had been like a vessel sailing on an even keel in the comparatively placid waters of commercial security, drawing for its development and forward movement on the motive and directive power of its own experience. In the thirties, however, the economic blizzard struck the craft and struck it hard. It nearly foundered. The second world war created conditions which meant better prices for the commodity, but the Indian coconut industry could not cope with the situation for, during the depression period, it had been nearly drained out of its vitality.

It was in these circumstances that the Indian Central Coconut Committee was set up (in February, 1945) to take measures for the improvement and development of the Indian coconut industry, to rehabilitate it so that it may be rendered fit to serve the entire need of the country.

During the last twelve years of its existence the Committee has been able to achieve a great deal in the field of research and add substantially to the existing knowledge on coconut culture. It was, therefore, a very good idea on the part of the Committee to arrange for the compilation of this monograph which brings within its covers in an easily accessible form all available information on the subject.

I especially congratulate the Committee on bringing out this volume at this juncture when every effort is being made under the Second Five-Year Plan to step up the production of coconuts to make the country self-sufficient in this commodity. I hope that it will prove to be of inestimable value to scientific and extension workers and the intelligent farmers and help them forward in the battle of increased coconut production.

5TH JUNE 1958.

A. M. THOMAS,

Deputy Minister for Agriculture, Government of India.

PREFACE

A SERIES of monographs on the important crops of India are being programmed for publication by the Indian Council of Agricultural Research and the Commodity Committees. In pursuance of this programme I suggested at the 23rd meeting of the Indian Central Coconut Committee held at Ernakulam in March 1956 that a monograph containing complete information on various aspects of the coconut palm, including its morphology, anatomy, cytology, physiology, cultural practices, and control of pests and diseases, be brought out. This suggestion was readily accepted by the Committee, and Dr. K. P. V. Menon, Director, Central Coconut Research Station, Kayangulam, and Dr. K. M. Pandalai, Joint Director, Central Coconut Research Station, Kasaragod, were asked to undertake this work. The authors have based their work largely on a monograph entitled *The Coconut* written in 1938 by Dr. J. S. Patel the then Oilseeds Specialist to the Government of Madras. However, since the publication of Dr. Patel's Monograph a considerable mass of literature about the different aspects of coconut palm bearing on the special interests of growers, research workers and industrialists has accumulated. In 1945, the Indian Central Coconut Committee was set up and it established two Central Coconut Research Stations — one at Kasaragod and the other at Kayangulam. Problems relating to breeding, cultivation, manuring, etc., have been tackled at the Research Station at Kasaragod, and those pertaining to diseases and pests at the Research Station at Kayangulam. A large number of scientific papers based on the work done at the Research Stations at Kasaragod and Kayangulam have been published in *The Indian Coconut Journal* and the *Coconut Bulletin* issued by the Committee during the last twelve years. Research on coconut has also made considerable progress during the last twenty years in Ceylon, Philippines, New Guinea, Trinidad and Jamaica. Outstanding work has been done on coconut and its problems in Ceylon and the Philippines. A monograph on coconut cannot be regarded as complete without reference to the work of distinguished scientists from the coconut growing countries. I am glad that Messrs. Menon and Pandalai have referred to the findings of the workers in other countries as well.

I congratulate Drs. K. P. V. Menon and K. M. Pandalai for their industry in compiling, consolidating and presenting a large mass of facts on coconut palm in this monograph. Dr. P. J. Gregory, Secretary of the Indian Central Coconut Committee, by interest in this work has materially contributed to it. Mr. C. M. John who was the first Director of the Central Coconut Research Station, Kasaragod, has carefully revised the text which has further been edited by Mr. K. M. Thomas, the retired Government Mycologist to the Madras Government and Director of Coffee Research Institute, Balehonnur, Mysore. Most of the photographs have been provided by Mr. K. K. Achary, Mr. V. P. Pachukutty, Artist-Photographers of the Central Coconut Research Station, Kasaragod and Indian Central Coconut Committee, Ernakulam respectively, and some by Mr. H. K. Gorkha, Photographer of the Indian Council of Agricultural Research. The lay-out of the illustrations has been prepared by Mr. N. S. Bisht, Director of Art, Indian Council of Agricultural Research.

Coconut is a very important crop in south and eastern India, and occupies a position in the economy of the country. A number of important schemes have been started under the Second Five-Year Plan to step up its production. I feel that this volume, presenting as it does all available information on coconut culture, appears at a most opportune moment. It will prove of immense value to research and extension workers as well as to progressive cultivators, and will also be useful to agricultural students as a standard text-book not only in this country, but also in other countries of South East Asia where coconut palm is grown.

M. S. RANDHAWA, D.Sc., F.N.I., I.C.S.,
Vice-President, Indian Council of Agricultural Research.

New Delhi,
30th July 1958.

AUTHORS' PREFACE

THIS publication owes its origin to the inspiration and initiative of Dr. M. S. Randhawa, D.Sc., F.N.I., I.C.S., President of the Indian Central Coconut Committee and Vice-President of the Indian Council of Agricultural Research. He felt that after the publication of *The Coconut — A Monograph* by Dr. J. S. Patel in 1938, there has not been any compilation embodying information which had become available in the different coconut growing countries which would be useful both for the coconut grower and for the research worker. The bibliography cited in this publication would bear evidence to the fact that the last two decades have seen the accumulation of a considerable amount of literature about the different aspects of the coconut, from the point of view of the grower, the research worker and the industrialist. The necessity, therefore, for the consolidation and presentation of all available facts pertaining to the coconut in a readily available form in one publication was apparent.

The three standard books on the coconut, *viz.*, *The Coconut Palm* by Sampson, 1923, *The Coconut* by Copeland, 1931, and *The Coconut — A Monograph* by Patel, 1938, have been freely consulted and form the basis of the present work. The authors have freely quoted textual portions and reproduced text figures from the above, wherever it was felt that any change from the original was unwarranted. Other publications on coconuts such as *The Diseases of the Coconut Palm* by Briton Jones, 1940, *Coconut Cultivation* by C. M. John, 1952, and several important published papers from research workers in the Philippines, New Guinea, Trinidad, Jamaica, Ceylon, etc., notably those of Dwyer, Martyn, Child, Cooke, Salgado, Liyanage, Nathanael and others, have also been freely made use of and the authors would like to record their deep indebtedness to them. Thanks are due to Messrs. M. Malye and C. M. John of the Potascheme, India, for making available the results of their coconut fertilizer demonstration trials.

Had it not been for the invaluable and unstinting assistance that the authors received from their colleagues, who supplied material in their respective fields, the task would have been almost impossible. Particular mention should be made of the contributions made by Dr. K. K. Nirula, Dr. K. Radha, Messrs. E. J. Verghese, S. R. Gangolly, M. M. Krishna Marar, T. A. Davis, U. K. Nair, A. P. Anandan, J. Antony, H. Sankarasubramoney, A. N. Nagaraj, Dr. C. Kurian, K. Satyabalan and M. P. Sankara Narayanan. Several other junior colleagues in the Central Coconut Research Stations at Kasaragod and Kayangulam have also contributed to the preparation of this publication, to whom sincere and heartfelt thanks are due. The authors record with pleasure their thanks to Dr. P. J. Gregory, Secretary, Indian Central Coconut Committee, for his ready and willing co-operation in their task. They would also like to express their indebtedness to the Directors of Agriculture and of Research Institutes of the different coconut growing countries for their ready response in supplying information regarding the work done on the coconut in their respective countries. The authors are highly indebted to Shri C. M. John, formerly Director, Central Coconut Research Station, Kasaragod, now Technical and Agricultural Adviser, Potascheme, India, and Shri K. M. Thomas, Retired Government Mycologist, Madras and retired Director of Coffee Research, for scrutinising the manuscript and offering valuable suggestions. Most of the colour transparencies used in this book were taken by Shri T. A. Davis, Plant Physiologist of the Central Coconut Research Station, Kayangulam.

In the preparation of this monograph the authors have tried to keep the broad object of giving a critical account of the present knowledge on each subject dealt with and for this, references have been quoted wherever possible. The authors have been obliged to sift the big volume of literature and select references that are more familiar and those that are more relevant to the subject under discussion. In this process some omissions were inevitable but an earnest attempt has been made to reduce such omissions to the minimum. Any research worker whose valuable work might have been overlooked is requested to kindly forgive the omission and to bring to the notice of the authors such omissions and errors for rectification in future editions.

ERNAKULAM,
14TH APRIL 1958.

K. P. V. M.
K. M. P.

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CHAPTER I

THE COCONUT—ITS IMPORTANCE—ITS ORIGINAL HOME

The coconut palm, *Cocos nucifera* Linn., with its tall, slender and uniformly thick stem and massive crown with large number of leaves, bearing bunches of nuts in their axils is one of the most beautiful and useful trees in the world. It perhaps yields more products of use to mankind than any other tree. It is no wonder then that the palm is looked upon with reverence and affection by the inhabitants of the coconut producing countries and given such eulogistic epithets such as *Kalpa Vriksha* (Tree of Heaven), the Consols of the East, Mankind's Greatest Provider in the Tropics, Tree of Life, Tree of Abundance, Tree of Plenty, etc.

Each and every part of the coconut palm is useful to man in one way or another. A detailed account of the countless uses of this invaluable palm is given in Chapter XVII, the most important of them, however, being the following:—The tender coconut supplies a very popular, refreshing and satisfying beverage. The raw kernel is an important article of food. The oil from the nut is used in cooking and in the manufacture of soap and other toilet requisites. The coconut oil-cake or *poonac* is a valuable cattle feed. Fibre from the husk is used in the manufacture of coir ropes, mats and mattings. The trunk, otherwise called ' porcupine wood ', is used in house construction and furniture making. The leaves after plaiting are used to thatch houses. The juice obtained on tapping the inflorescence is rich in sugar and is converted into jaggery, sugar, vinegar and sweet or fermented toddy. The products of commercial importance are copra, oil, oil-cake, desiccated coconut and fibre.

The importance of the palm lies in the fact that not only does it supply food, drink and shelter, but it also provides raw material for a number of important industries. It is also essentially a crop of the small land holder who obtains cash for the purchase of necessities of life by the sale of coconut and coconut products. In the Philippines, 82·1 per cent of the total area under coconut is composed of small holdings with an average extent of about two hectares (about 5 acres). In India, the average holding is estimated to be less than an acre. In Ceylon, small holdings of less than 20 acres each account for over 80 per cent of the area under the crop. In Malaya, out of a total area of 6·0 lakhs of acres, 3·9 lakhs are composed of holdings of less than 100 acres in extent.

The coconut industry is intimately connected with the economic and domestic life of the inhabitants of the coconut growing countries. It provides employment and perhaps the only source of livelihood to tens of thousands of people. Thus in the Philippines, eight million people or more than a third of the entire population are dependent upon this industry for their livelihood. In India (W. Coast), according to Gopalan (1954), the coconut industry gives full or part-time employment to over 37 lakhs of people which form nearly 30 per cent of the total population of Kerala comprising the districts of Trivandrum, Quilon, Kottayam, Trichur, Kozhikode (Calicut), Cannanore and Palghat. In Ceylon, the coconut industry is the main source of livelihood and occupation of nearly 3 million of its population.

The importance of the coconut as a source of food is indeed overwhelming, though because of its commonplace nature it is often forgotten. In India, coconut is consumed in the form of tender nuts, raw kernel, copra, coconut oil and desiccated coconut. According to Gopalan (1951), the nut equivalent of coconuts and coconut products consumed in India comes to 2,893 million or about 84 per cent of the total production in the country. In Ceylon, the *per capita* consumption of coconuts is estimated at 140 nuts per annum which amounts to an annual consumption of about 1,000 million nuts out of an estimated production of 2,000 million. In the Philippines, 4 to 5 per cent of the production is reported to be consumed locally. Since dishes made from the coconut furnish fat, protein and some vitamins, they counterbalance some of the deficiencies inherent in the predominantly starchy foods consumed in the countries concerned.

Some of the coconut countries derive substantial revenue from the coconut industry. In the Philippines, it is the premier dollar earning industry, and exports of coconut products represent a sizeable portion in foreign trade. The value realised from the export of coconut products formed as much as 73·9 per cent of the total value of all exports of the country in 1947, but it declined to 38·6 per cent in the year 1953. In India, the annual production of coconut is valued at 540 million rupees, and coir products exported abroad earn the much needed foreign exchange. In Ceylon, the coconut industry is the largest, most broad-based and the most fundamental industry. Ceylon exports a greater tonnage of coconut products than tea and rubber. The value of coconut products exported from Ceylon in 1950 was nearly £21 million. In 1953, Malaya realised as much as 65·5 million dollars from the exports of coconut products.

The importance of the coconut in the economies of the producing countries as judged from the position of coconut products in exports of all merchandise is vividly brought out by the data recently compiled in respect of selected countries by the Food and Agriculture Organisation of the United Nations (1956) and extracted below:

Table 1.—Coconut products: Contribution (percentage) to the value of total exports of domestic products in selected countries

	1929–1933	1934–1938	1947–1950	1951–1954
Philippines	25·6	26·2	64·8	40·6
Indonesia	7·2	6·3	10·2	6·6
Ceylon	16·9	13·8	14·0	17·8
Malaya	4·5	3·4	4·2	2·9
New Guinea	71·7	30·9	58·3	68·6
Tonga	94·9	91·4	92·3	90·3
Fiji	21·0	14·9	24·4	25·2
North Borneo	6·2	4·6	8·2	12·1

Except in the case of Indonesia, North Borneo and Malaya the reliance of other countries on earnings from coconuts has always been substantial at all times during the period under review.

Considerable amounts are also invested in the coconut industry. In the Philippines, the investment is estimated at 442·4 million pesos. In Ceylon, in 1949, 500 million rupees were estimated to be invested in coconut industry. Figures in respect of India are not available but there is no doubt that the investment would be very substantial.

Coconut is everything for the inhabitants of the Pacific Islands, an area studded with the palm. This extreme dependence has been put succinctly by Pieris (1954), thus: " Human life would become intolerable if there were no coconut palms. On the atolls it would become impossible. Nothing has been found to take its place and nothing is likely to be found in the foreseeable future ".

AREA AND PRODUCTION OF COCONUTS

World acreage

Statistics about the world acreage and production of coconuts are generally meagre, incomplete and of doubtful accuracy. There does not appear to be any uniform standard for estimating the area or production of the crop. In some countries, the entire area where coconut is grown is reckoned as the area under the crop, irrespective of the intensity of the plantation or the fact that it is largely raised in association with other crops. In other countries the acreage is calculated on the number of trees as the basis. Similarly the production figures are also subject to considerable inaccuracies and therefore can be taken to be only as rough estimates.

An early ambitious attempt at estimating the world acreage under coconut was made by Leo Schnurmacher in 1938. The figures gathered by him are given in the following table. The main coconut producing areas are indicated in Fig. 2.

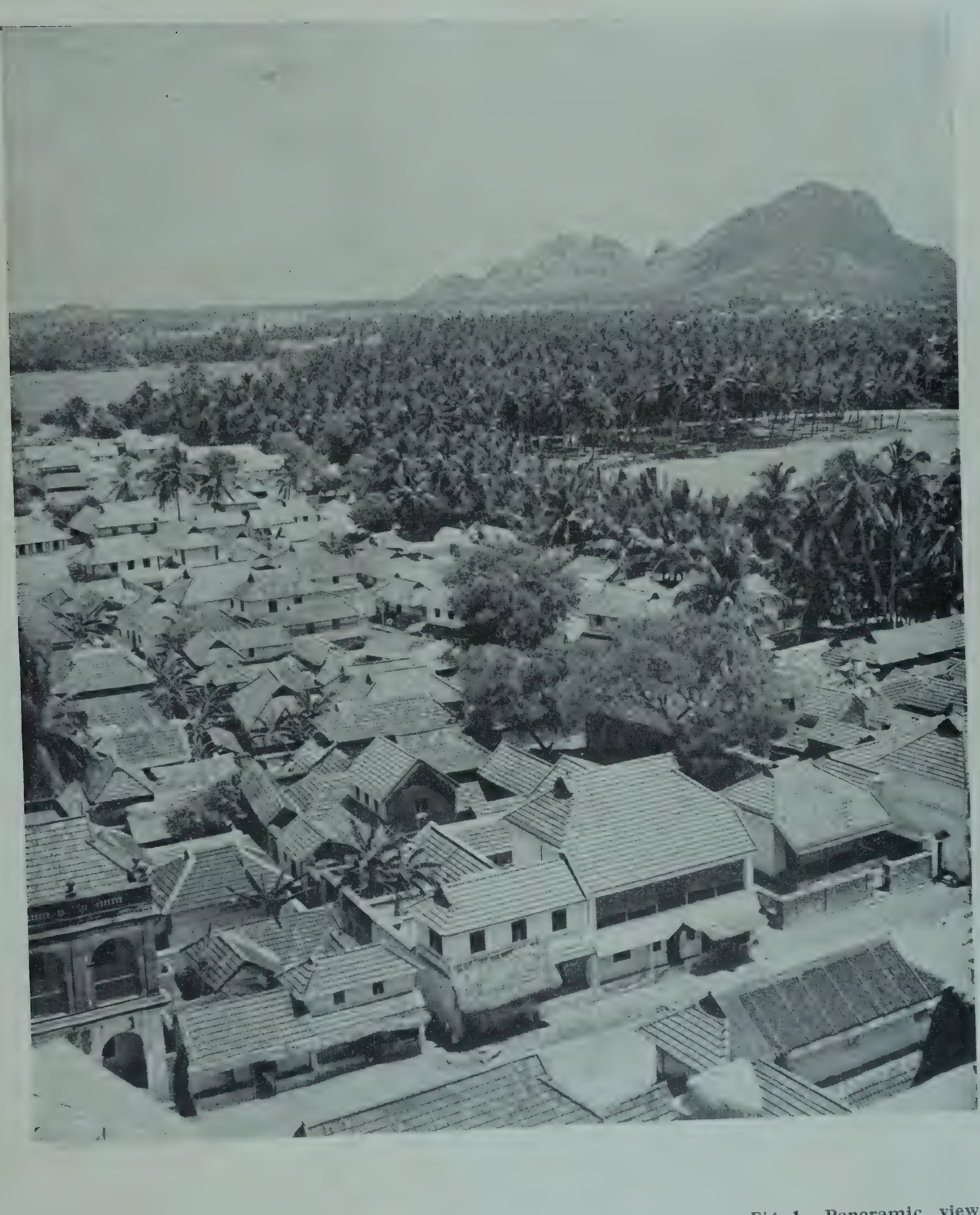
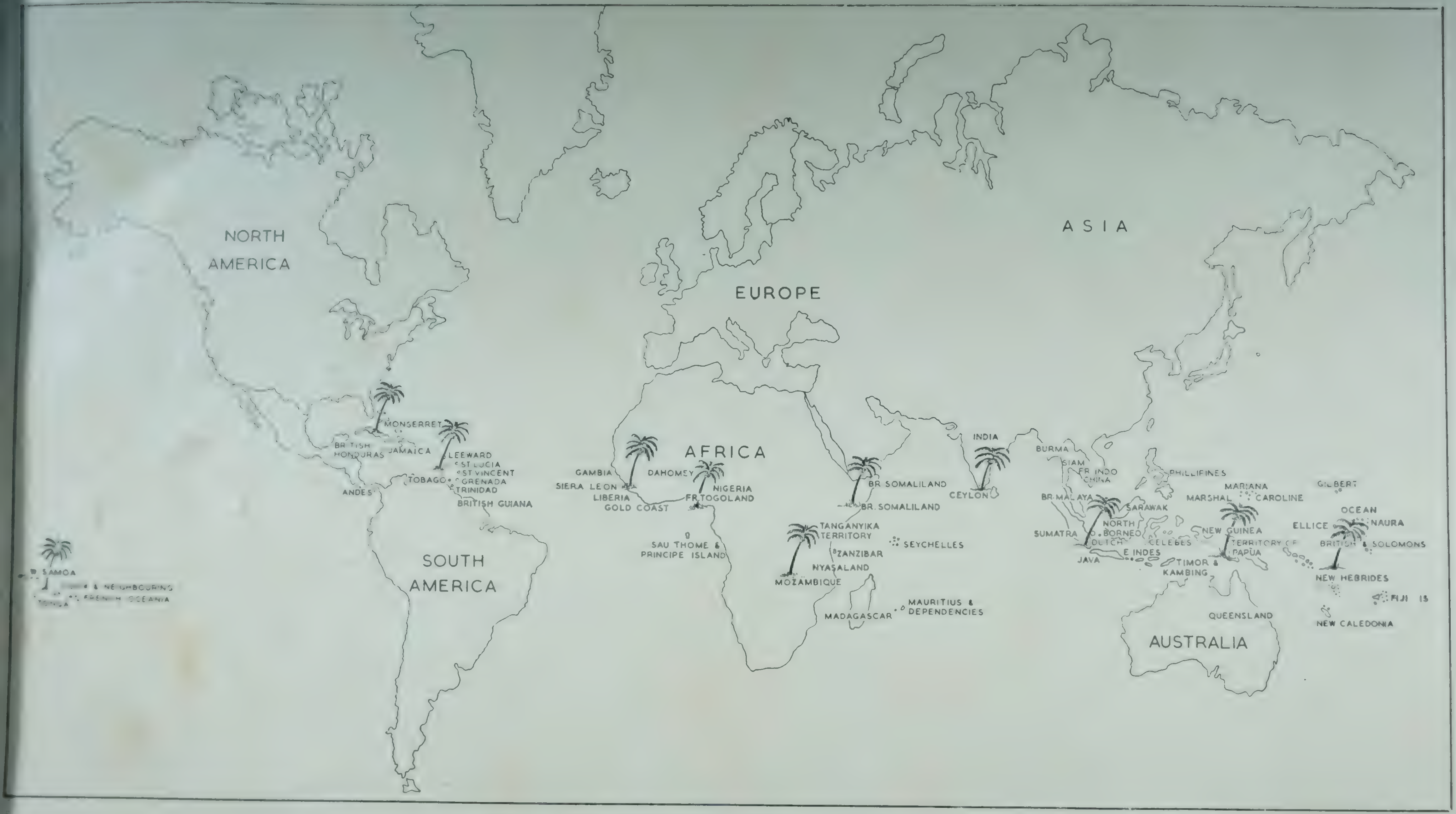


Fig. 1. Panoramic view of coconut gardens in the Southern tip of the Indian Peninsula



COCONUT PRODUCING AREAS OF THE WORLD

NORTH AMERICA
SOUTH AMERICA
EUROPE
AFRICA
ASIA
AUSTRALIA
BRITISH HONDURAS
JAMAICA
MONSERRET
LEEWARD
ST LUCIA
ST VINCENT
GRENADA
TOBAGO
TRINIDAD
BRITISH GUIANA
ANDES
GAMBIA
SIERA LEON
LIBERIA
GOLD COAST
DAHOMEY
NIGERIA
FR. TOGOLAND
SAU THOME & PRINCIPE ISLAND
BR. SOMALILAND
BR. SOMALILAND
TANGANYIKA TERRITORY
ZANZIBAR
NYASALAND
MOZAMBIQUE
SEYCHELLES
MADAGASCAR
MAURITIUS & DEPENDENCIES
INDIA
CEYLON
BURMA
SIAM
FR. INDO CHINA
BR. MALAYA
SUMATRA
NORTH BORNEO
SARAWAK
DUTCH
E INDES
CELEBES
JAVA
TIMOR & KAMBING
PHILLIFINES
MARIANA
MARSHAL
CAROLINE
NEW GUINEA
TERRITORY OF PAPUA
QUEENSLAND
GILBERT
OCEAN
ELLICE
NAURA
BRITISH & SOLOMONS
NEW HEBRIDES
FIJI IS
NEW CALEDONIA
SAMOA
& NEIGHBOURING
FRENCH OCEANIA
TONGA

Fig. 2. World map showing coconut producing areas

Table 2.—Estimated world acreage of coconut palms

Country	Acreage ('000 acres)
MALAYAN ARCHIPELAGO	
Netherlands Indies	2,944
Philippine Islands	1,571
North Borneo	47
Sarawak and Brunei	10
Papua	48
New Guinea	296
Timor and Cambing	2
	4,918
SOUTH-EAST ASIA	
Malaya	609
Siam	126
Indo-China	86
	821
INDIA AND CEYLON	
India	1,490
Ceylon	1,100
	2,590
PACIFIC TERRITORIES	
Gilbert and Ellice Islands	102
Nauru	1
Mariana, Caroline and Marshall Islands	83
Solomon Islands	63
New Hebrides	25
New Caledonia	7
Fiji Islands	131
W. Samoa	53
Tonga Islands	54
Cook Islands	....
French Oceania	64
Guam	18
	601
EAST AFRICA AND NEIGHBOURING ISLANDS	
Portuguese East Africa (Mozambique)	183
Madagascar and Dependencies	37
Tanganyika Territory	62
Kenya	....
Zanzibar	55
Seychelles	28
Mauritius	3
	368
WEST AFRICA	
Gold Coast	4
Nigeria	1
Dahomey	....
Portuguese Guinea	24
Fr. Togoland	24
Angola	8
San Thome and Principe	9
	70

Table 2.—Estimated world acreage of coconut palms—*(Contd.)*

Country	Acreage ('000 acres)
WEST INDIES	
Trinidad and Tobago	50
Jamaica	40
St. Vincent	4
St. Lucia	5
Grenada	1
St. Kitts-Nevis	1
Dominica	2
Virgin Islands	....
Puerto Rico	9
	112
CENTRAL AND SOUTH AMERICA	
Mexico	78
British Guiana	22
Panama	13
Honduras	11
British Honduras	8
Columbia	2
Surinam	2
	136

In round figures the total acreage is put at about nine million acres of which the Malayan Archipelago accounts for over fifty per cent of the world acreage under coconut followed by India and Ceylon. In the light of the latest figures available for some coconut growing countries, the world acreage and, production of coconut appear to be as follows.

Table 3.—World acreage and production of coconuts

Country	Area (in million acres)	Production (in million nuts)	Years to which estimates relate
Philippines	2·45	4,916	1954
India	1·59	4,151	1954–55
Indonesia	1·50	3,200	1936–37
Ceylon	1·07	2,147	1954
Malaya	0·60	850	1940
British South Sea Islands	0·60	750	1929–30
Others	0·70	900	1929–30
Total	8·51	16,914	

Acreage and distribution in India

The area and production of coconuts in the different states of the Indian Union according to the latest statistics available are given below :—

Table 4.—Area and production of coconuts in India*

State	Area in acres	Production of coconuts (in thousands)
Kerala	10,98,502	27,41,141
Madras	1,29,319	4,18,214
Mysore	2,14,752	5,68,478
Andhra	83,708	3,11,241
Bombay	20,331	30,021
West Bengal	16,500	22,205
Orissa	10,468	29,377
Laccadive Islands	7,269	15,474
Assam	2,000	12,787
Andamans & Nicobars	4,293	2,500
Total	15,87,142	41,51,438

* Estimated from District-wise figures reported by the State Governments for 1954-55.

The strip of land on the West Coast of India lying between the Arabian Sea and the Western Ghats, comprising the districts of South Kanara, Cannanore, Kozhikode, Palghat, Trichur, Kottayam, Quilon, Trivandrum and Kanyakumari is the most important coconut area in India.

HOME OF THE COCONUT

The intricate problem of determining the home of the coconut has been discussed by a host of workers (Paget, 1929; Cook, 1910; Mayuranathan, 1938). A perusal of these contributions revealed that while they presented considerable evidence and enriched our knowledge on the subject, the original home of the coconut, still remained enshrouded in mystery. The wide dispersal of the palm, its antiquity in most regions of the tropics, conflicting views on its origin presented by research workers and the lack of convincing and conclusive evidence in support of its origin in a particular region, had rendered the task very difficult. However, it is undoubtedly interesting to reconsider the problem in the light of new evidence available from Agronomy, Botany, Geographic history, Philology, etc.

Burkill (1935) presented three theories prevalent on the origin and distribution of the coconut. According to the first, the palm came from the stock which gave rise to the American members of the genus *Cocos* and originated in the northern end of the Andes in Tropical America from where it was taken into the Pacific. The second theory is that from a place of origin on the coasts of Central America, the equatorial currents of the sea transported it to the Pacific Islands. According to the third, which is more generally accepted, it is supposed to have originated in South Asia or in the Pacific from where it reached America.

Mayuranathan (1938) and Child (1953) pointed out that in tracing the home of the coconut, its intensive cultivation, its concentration, occurrence of greater number of varieties and species, prevalence of a large number of names for the coconut, record of fantastic legends connected with its origin, discovery of fossil coconuts, prevalence of religious customs involving the coconut in worship and ceremonials, etc., in a particular region have little or no bearing. It appears, therefore, necessary in deciding the home of the coconut, to consider the whole area of its dispersal and then re-examine the connected theories and evidence.

TROPICAL REGION—THE HOME OF THE COCONUT

Burkill (1935) pointed out that the tree demanded certain conditions for its growth, viz., aeration of the root provided by the movement of the air through the sandy soil produced by rising and falling tides; moisture at the crown afforded by the sea breeze; and nearness to water or sea for its efficient dispersal. According to Mayuranathan its high degree of tolerance for salinity and saline moisture, and high degree of adaptability to dispersal by sea proved that it is a sea-side plant. Blatter (1926), however, was of the opinion that it could not altogether be termed an exclusively littoral plant as it had been met with far inland at Merida of Yucatan, at Patna in India and Timbuktu in Africa. Humboldt (1817) cited its cultivation in Rio Magdalena more than a hundred leagues from the coast. Blatter indicated that, wherever the coconut ventured beyond the limits of the tropics, it lost its elegance, power of productivity and sickened off and died after eight or ten years. In support of this, he pointed out, that in the Sandwich Islands at the edge of the Torrid Zone, the coconut had a ' mean ' look. He, therefore, stated that the plant could be grown successfully only in the tropics at medium and low elevations where there was either high water table or facilities for irrigation.

It would, therefore, appear that the area of equatorial calms characterised by light and varied winds, heavy and regular rainfall, extreme humidity, equable climate and warmth without undue heat, prevalent in the coasts of the tropics could alone be the home of the coconut.

The palm admittedly had a far wider spread in the tropics than most other crop plants. Sampson (1929) dealing with the distribution of this crop pointed out that it was indigenous or introduced very early in the history of the world in India (Madras, Bombay, Bengal, Orissa and Mysore), Ceylon, Burma, Africa (Zanzibar, Tanganyika, Kenya), Federated Malay States, Java, Sumatra, Borneo, Ocean Islands, Papua, New Guinea, Trinidad, British Honduras, Ellice Islands, Fiji, Gilbert Islands, Gold Coast, Grenada, Jamaica, Nauru Islands, New Hebrides, St. Kitts, Sarawak, Seychelles, Solomon Islands and Monserrate. According to him, its introduction into Gambia, Mauritius, Nigeria, Nyasaland, St. Vincent and Sierra Leone was much later and its introduction into Tropical Australia was most recent. It will, therefore, be interesting to consider to which of these places the origin of the coconut could be assigned.

(*a*) ITS ORIGIN IN THE TROPICAL NEW WORLD

1. The American continent

Conspicuous absence of the species of *Cocos*, other than the coconut, either in its wild or cultivated form anywhere else except on the continent of America and the discovery of a grove of coconuts by Oviedo (cited by Ridley, 1930) at the Isthmus of Panama at the time of discovery of America by Columbus in 1515, led many botanists to believe that it was of American origin. Merril (1936, 1937) also believed that the coconut having no affinities to the Asiatic genera of palms could not have evolved in Asia. Grisebach (1864, 1866, 1872) entertained no doubt on its American origin. Cook (1910) was the most emphatic advocate of this theory and he believed that the primitive agricultural people from America distributed it on the shores of the islands of the Pacific and Indian Oceans. Thor Heyerdahl (1954) also adduced evidence to show that the coconut was introduced into the Polynesian Islands from Peru. Martius (1850) was among the first who placed the probable origin of the coconut on the West Coast of Central America somewhere near the Isthmus of Panama.

The bulk of the botanical evidence in favour of its American origin, had to be abandoned later for the following reasons: the discovery of some new forms of palms of the tribe *Cocoineae* in South Africa and Madagascar; the existence of the coconut in Africa at the time of its discovery by Vasco da Gama in 1498 (cited by Child, 1953); the record of cultivation of the coconut in about 300 B.C. in Ceylon (*Rep. Coc. Com. Ceylon*, 1949) and in India in the post-vedic times (Mayuranathan); the discovery of fossil *Cocos* in the Pliocene deposits (one to fifteen million years ago) in North Auckland in New Zealand (Hill, 1929) and in the Eocene deposits (fifteen to forty million years ago) in the deserts of Rajasthan in India (Kaul, 1951) very much earlier than the discovery of America.

The west coast of America, as pointed out by Mayuranathan, was dry and not conducive to the growth of the coconut. This was proved from observations of Seemann (1856, 1865, 1868) who cited several instances of failure of trials in cultivation of the crop in the Panama area. Conceding that it originated there, Mayuranathan found it difficult to explain why it failed to reach the West Indies and the shores of the Caribbean seas at the time of discovery of America, till the Spaniards introduced it on the

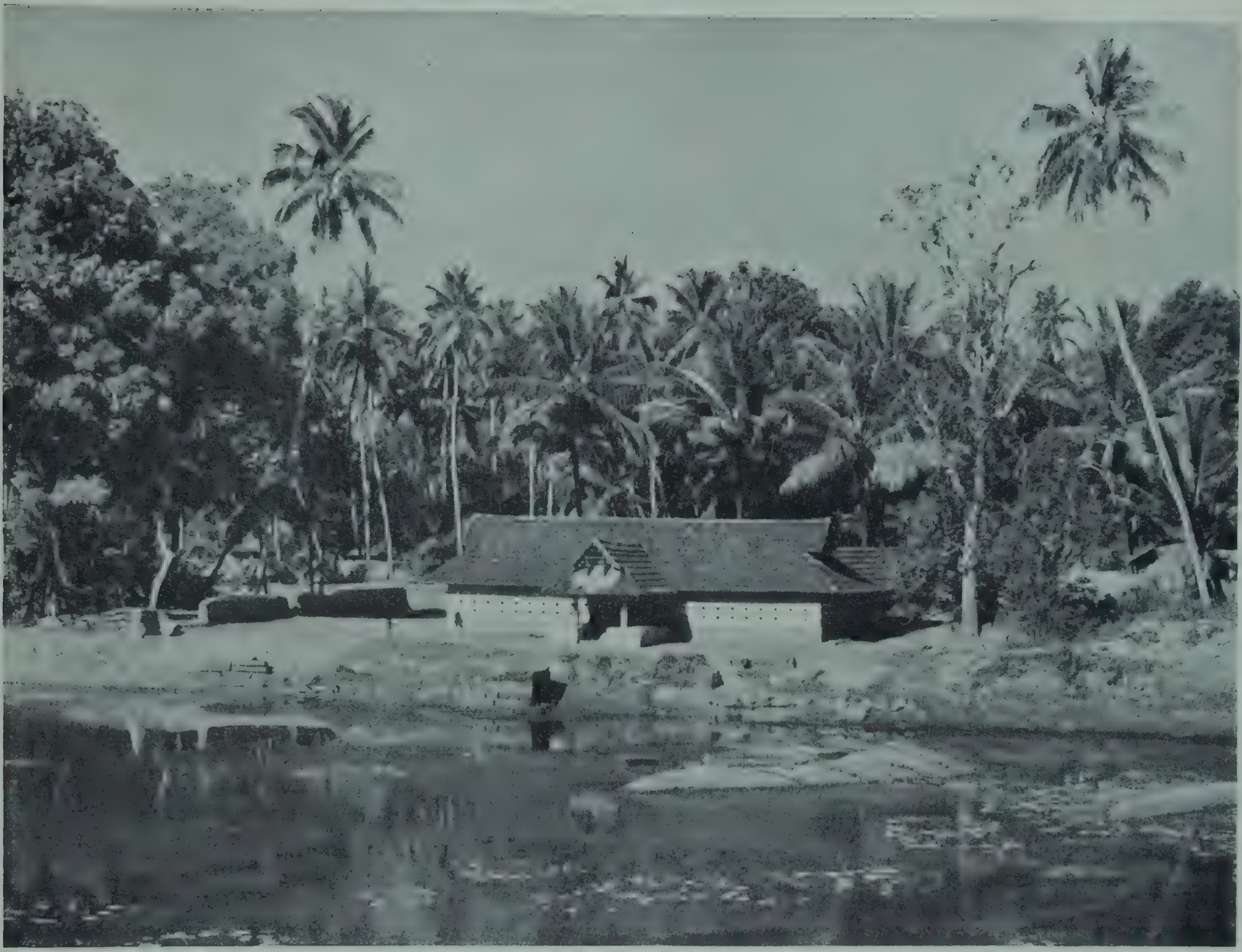


Fig. 3. A typical scene of a coconut area in Kerala

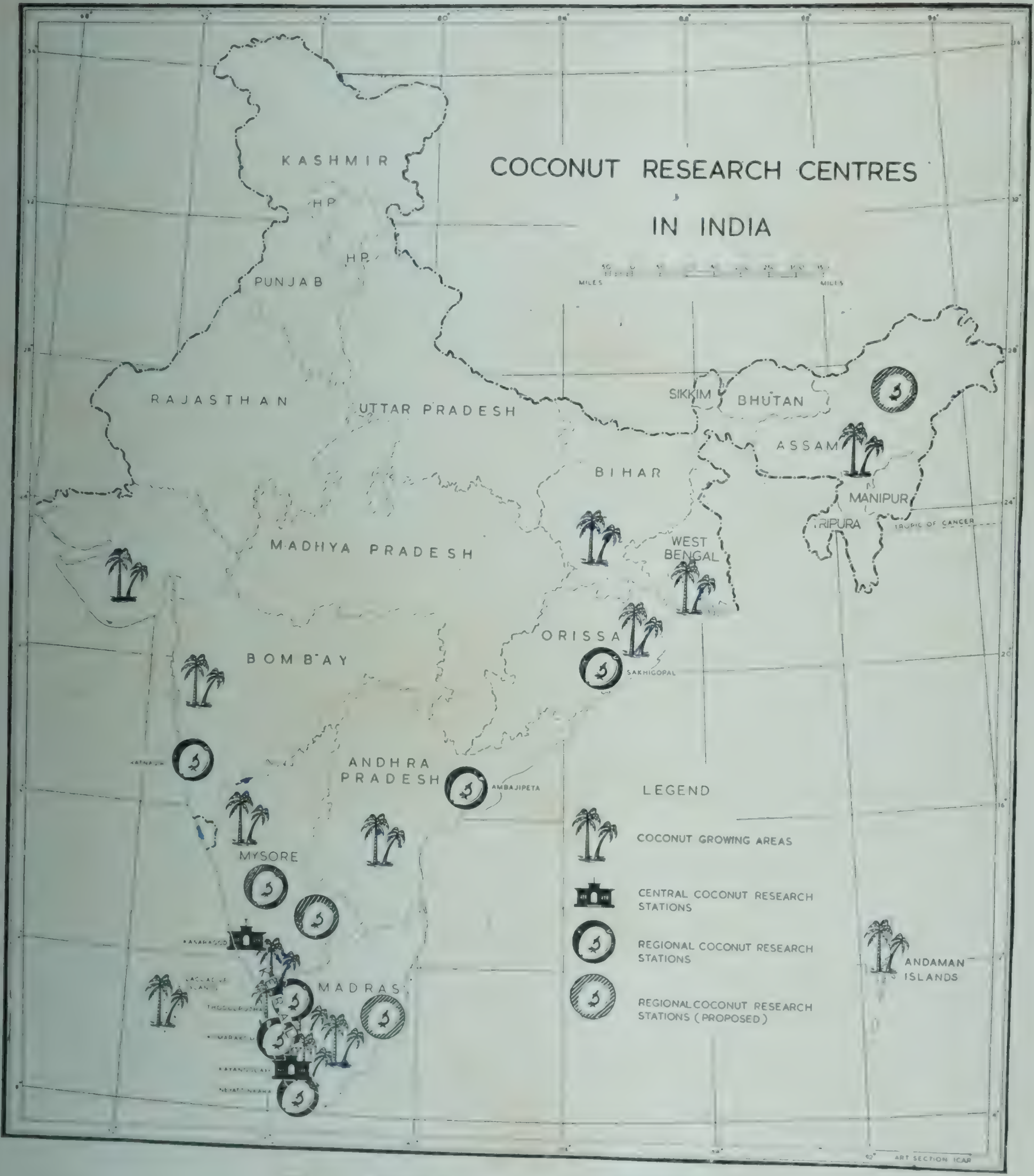

COCONUT RESEARCH CENTRES
IN INDIA
MILES
MILES
KASHMIR
H.P.
H.P.
PUNJAB
RAJASTHAN
UTTAR PRADESH
SIKKIM
BHUTAN
ASSAM
BIHAR
MANIPUR
TRIPURA
TROPIC OF CANCER
MADHYA PRADESH
WEST BENGAL
ORISSA
SAKHIGOPAL
BOMBAY
ANDHRA PRADESH
AMBAJIPETA
MYSORE
KASARAGOD
MADRAS
ANDAMAN ISLANDS
LEGEND
COCONUT GROWING AREAS
CENTRAL COCONUT RESEARCH STATIONS
REGIONAL COCONUT RESEARCH STATIONS
REGIONAL COCONUT RESEARCH STATIONS (PROPOSED)
ART SECTION ICAR

Fig. 4. Centres of coconut research in India

southern shores of the Caribbean seas and the West Indies, and the Portuguese into Bahia and Southern parts of Brazil (Blatter, 1926). He also failed to understand how the coconuts could reach distant places in the Pacific and Indian Oceans considering that the American aborigines had neither the skill nor the need to journey beyond the vicinity of their shores.

Its introduction in America in times later than its record of cultivation elsewhere as pointed out by Mayuranathan, was also evident from the lack of native names for the coconut as well as the traditional use of the coconut in the ceremonials among the aborigines and settlers of tropical America. Federici (cited in *Rep. Coc. Com. Ceylon,* 1949), thought that the palm was brought to the West Coast of America from Polynesia. This is amply proved from the statement of Jennes (1933) who believed that the coconut plants noticed at the Isthmus of Panama originated from nuts carried there by Polynesian immigrants in comparatively recent times.

2. Polynesian and Pacific Islands

The Polynesian and the other numerous islands of the Pacific have attained at present the highest development in regard to the cultivation of the coconut. Mayuranathan pointed out that with the Polynesians as well as the islanders of the Pacific, the coconut was not only known ever since these islands came to be inhabited, but had also occupied a higher ceremonial status being worshipped as one of their Gods. Though established in other lands, he showed how the coconut had attained its highest degree of development in Polynesia. According to him the cult of the coconut was so ingrained in the daily life of the Polynesians that they, like the Malays, had definite names for the nut pertaining to various stages of its growth. According to Rangi Hiora (1932) thirteen names distinguished the stages of development of the coconut from the female flower to the dried seed nut. Brown (1931) enumerated over fifty varieties of coconuts in Marquesas Islands, where every variety was known under a distinct native binomial, while not more than two names were known in America. All the above facts indicated beyond doubt, that the cultivation of the coconut in these islands was of much earlier origin than that in America, although, assigning its origin to these islands was rather difficult. The geographic history of the formation of these islands as pointed out by Mayuranathan, showed that these being of coralline or volcanic nature, represented geographically new lands and for this reason the origin of the coconut cannot be assigned to them.

The above evidence, therefore, helps to rule out the probability of its origin in America or other parts of the new world.

(*b*) ORIGIN IN THE OLD WORLD TROPICS

The possibility of its origin in the Old World Tropics may now be considered. Merril (1936, 1937) contended that, although, the place of origin of the coconut is somewhat a mystery, it was undoubtedly a native of some part of the old world tropics. Burkill, Patel (1938) and Mayuranathan pointed out how research workers were all agreed that the home of the coconut was somewhere between Zanzibar and New Caledonia. An examination of the facts in this connection would indicate to which part of this region the home of the coconut could be assigned.

1. The Indian Ocean

The notable areas in the Indian Ocean include tropical Africa, India, Ceylon and the prehistoric area now under the seas in the Western part of the Indian Ocean. The claims of these areas may now be considered.

(*i*) *Prehistoric area now under the seas*

Patel pointed out that it was generally recognised that the prehistoric area from Madagascar to the Philippines should have been the home of the coconut. Beccari (1913) and Werth (1938) adduced evidence to assign the origin of the coconut to the submerged lands in the Indian Ocean in South West Asia. Burkill, however, did not agree with this view. Moreover, the general opinion of other workers also was not in favour of its origin in this area.

(*ii*) *Tropical Africa*

It would appear that none of the workers thought of assigning its origin to Africa. According to Mayuranathan, the Arabs from very early times called it an Indian fruit. Chiovenda (1923), an Italian historian, interpreted certain references in the work of the Arabian historians, Ibn Wahab, Abu Zaid and Alibiruni as indicating that the original home of the coconut was not far from India. Child (1953) has suggested its possible introduction there, by the Arabs who were trading with India, or through sea drift. The biological evidence presented by Lepesme (1947) pointed out that the coconut could never have originated there.

(iii) Ceylon

The coconut was of ancient origin in Ceylon (*Rep. Coc. Com. Ceylon*, 1949) and its cultivation there was as early as 300 B.C. Consequently, coconut was known there by a variety of names, mostly derivatives of the names by which it is known in India. Mayuranathan believed that the Singhalese names *Pol* and *Nirali* for the coconut were probably derived from the Sanskritic *Phala* and *Narikela* respectively, while the names *Kotta Pol* for the dry coconut and *Kurumba* for the immature fruit were derived from the Tamil names *Kotta thengai* and *Kurumai* respectively.

According to Patel, a leper king of Ceylon in the hoary past, seeing the palms flourishing almost in a wild state on the Malabar Coast is said to have been instrumental in its cultivation there. Mayuranathan cited a Ceylonese legend according to which, the coconut is supposed to have been brought to India from *Naga Loka*, the blissful region beneath the sea, by an illustrious king for worship, from where it was introduced into Ceylon. This theory that the coconut was not indigenous to Ceylon was also emphasised by others (*Rep. Coc. Com. Ceylon*, 1949).

(iv) India

Considerable historical evidence is available to prove the antiquity of the coconut in India. According to Mayuranathan, Cosmos writing about the coconut in the sixth century, described it under its Sanskrit name. He also pointed out that John Monte Carvino and Marco Polo in the thirteenth century considered it an Indian fruit. He cited instances of reference to the coconut in post-vedic works, viz., *Mahabharata, Ramayana, Vishnu, Matsya, Markhandeya* and *Brahmanda Puranas*. He cited a reference to it in the ancient Tamil work *Poranarattupadai* and post-vedic works like the *Tantras* where it had been referred to as a favourite of Lord Shiva. He mentioned instances of worship in India to *Varuna*, the Lord of the Seas, represented by a pot of water with a coconut placed over it. Offering of the coconut to the seas in worship on the coconut day (*Narial Poornami day*) is still a popular event with the inhabitants of the Konkan Coast. Menon (1933) pointed out a popular belief that the coconut represented *Deva Vriksha* or ' Tree of Heaven ', brought down by Lord Parasurama for the prosperity of the people of Malabar Coast. This strip of land is known as " Kerala " which literally means the land of the coconut.

While its antiquity in India is fairly well established, its origin in India remained disputed for many reasons. Although most of the post-vedic works contained references to the coconut, the Vedas — the oldest work of the Hindus — did not. This indicated a later introduction possibly in the post-vedic period. Apart from this, its possible introduction into India by oceanic currents in the monsoon drift from Malayesia cannot altogether be ruled out. Its later origin in India is supported by the fact pointed out by Bartlett (1927) that among the names of the coconut in Malaya, those of Sanskritic derivation were of a later origin than others already prevalent there. This would indicate that the coconut was introduced into India, during the post-vedic period and that in spite of the discovery of fossil *Cocos* species in Rajasthan (Kaul, 1951), India cannot be considered as the original home of the coconut. According to geographical history, Rajasthan desert (Wadia, 1919) was once covered over by the sea and it is possible that remnants of trees could have been brought down there by oceanic currents.

2. South-East Asia

The above-mentioned facts leave the claim of the region of South-East Asia comprising Malayesia and Melanesia as the only probable home of the coconut. The former according to Mollengraph, an eminent Dutch Geologist, cited by Merril (1936), comprised the two continental regions and an intermediate group of islands. The first consisted of continental areas of the Asiatic banks which included the Malayan Peninsula, Sumatra, Java, Bali, Borneo and the Paluvan Calmian group of the Philippines. The second continental area of the Australian banks included the ancient continent of Papua (Eastern New Guinea). The insular group of islands comprised the unstable area between the continental banks consisting of lesser Sunda Islands, Moluccas, Gilolo, Celebes and all Philippines except the Paluvan Calmian group and had been subjected to great upheavals and depressions from early times, thus excluding the possibility of the origin of the coconut there. The Melanesian region extended from the equator southwards to the tropic of Capricorn and between 145° to 189°E. longitude roughly extending from New Guinea to the Fiji Islands.

It is in this region that the coconut had attained its highest development. Besides this, as pointed out by Wegner (1924), the equatorial climate of Malayesian region which was conducive to the growth of the coconut had also been constant through ages. This region according to Merril (1936, 1937), formed an important centre of the origin of plant and animal life. The biological evidence is also in favour of its origin in this region. Child (1953) cited a close biological association between the coconut and certain animal species like the Robber Crab (*Birgus latro*), which was specific on coconuts. He believed that its association with the crop could be considered as long-standing. The chemical examination of the fat of this crab revealed that it closely resembled coconut oil while it had very little affinity towards animal fat. He advanced a plea that it could reasonably be presumed that when the coconut spread from its original habitat to other areas, it carried with it these crabs and, therefore, a survey of the spread of the crab would afford some clues to locate the original home of the coconut. A careful examination of the spread of the crab showed that it extended from Cocos Keeling Islands as far as Purdy Islands in the Bismark Archipelago and from New Hebrides to the Polynesian Islands of the Pacific in this region. Child also observed that a number of insect species which are specific to the plant could afford clues for locating its place of origin. He was of the opinion, that the areas where the number of insect species specific to the coconut are at its maximum, could be suspected to be the place of origin of the plant. He cited results of Lepesme (1947) which indicated that 90 per cent of the insects specific to coconuts were met with in Melanesia, while in Africa and America, it was only 4 per cent and 20 per cent respectively, which helped to assign the Melanesian region as its probable place of origin.

It is in this region that the coconut was known by the maximum number of names. Heyne (1927) recorded that there are 180 names for the coconut in the Dutch East Indies mostly known by one or more variants of the names, viz., *Niyur, Nira, Nio, Niog, Nyol* and a host of derivatives too numerous to mention. In addition, there were many legends connected with the coconut prevalent in this region, as pointed out by Hides (1937) on the antiquity of the coconut in New Guinea.

The weight of evidence is, therefore, in favour of the original home of the coconut being located somewhere in South East Asia. To trace its precise original home further and to localise it, appears to be merely speculative, although, DeCandolle (1885) traced it to the Dutch East Indies, Vavilov (1935) assigned it to the Malayan region (Siam, Malaya and Java), Mayuranathan traced it to the North West of New Guinea and Child, based upon findings of Lepesme, considered it of Melanesian origin.

DISPERSAL OF THE COCONUT IN THE WORLD

Having originated at some place in South East Asia, the coconut would now appear to have moved eastwards towards the Pacific and further into America. Towards the west it moved to India and Madagascar over the calm tropical waters. Although it is often referred to as an ' ocean-going ' nut (Vanderlock, 1937) due to its capacity to float and to germinate even after floating in sea water for 110 days (Edmondson, 1941) the possibility of its dispersal through the agency of water alone, looks altogether improbable. The seed-nuts in salt water lost their viability after several days, due to infiltration of salt water into the husk (Weaver and Clements, 1929). This was confirmed from observations of Thor Heyerdahl (1952) who found that coconuts packed for the Kontiki expedition on the raft out of contact with sea water were found capable of germinating, while nuts stored below the raft were ruined on exposure to sea water. Therefore, the agency of man must also have been responsible to a large extent to its introduction and spread. This is significant from the fact that the Spaniards introduced it into the West Indies and the southern shores of the Caribbean sea, the Portuguese introduced it into Bahia and other parts of Brazil, Polynesian seafarers spread it to the different islands of the Pacific, the Arabs disseminated it on the African coast and the maritime Tamils together with the mariners of the Bengal coast distributed it into the lands of the Indian Ocean.

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CHAPTER II

GENERAL MORPHOLOGY

The coconut belongs to the family of palms, *Palmae* included under the lower group of flowering plants known as the monocotyledons. It occupies a conspicuous position in the vegetable kingdom owing to certain features characteristic of the palms, viz., comparatively slow growth ; an unusual thickening at the base of the trunk giving mechanical rigidity; generally unbranched, erect, cylindrical, pillar-like stem, covered with heavy scars of old leaf bases; a compact magnificent crown of gigantic, feathery, glossy, thick-cuticled leaves sheathed at the base providing firm attachment to the stem, orientated at the top of the trunk rendering a natural beauty and elegance; a branched inflorescence enclosed in a sheath collectively known as the spadix; the absence of tap root and the continually growing terminal bud commonly known as the ' cabbage '.

A brief botanical description of the palm is given below:

Cocos nucifera Linn.

The genus *Cocos*, formerly included besides *Cocos nucifera* Linn. over thirty other species mostly confined to Central and South America. It is, however, now usual to regard one of them which is cosmopolitan in the tropics as a monotypic genus containing only *Cocos nucifera* Linn. — the Coconut, other species having been assigned to several new genera.

The coconut is cultivated in the warm damp regions of the tropics and is particularly distributed on all tropical shores. Its fibrous fruit is capable of drifting long distances uninjured ; hence it forms a characteristic feature of marine inland vegetation and indeed probably became widely distributed in early times.

It is a tall, stately, unarmed palm growing to a height of 12 m to 24 m. The trunk is stout, flexuous, annulate, rarely stands vertically, but makes a gradual curve, rising from a swollen base surrounded by a mass of adventitious roots. The stem is marked by rings of leaf-scars which are often not prominent at the base.

Leaves are large, long, pinnatisect, borne on the crown; leaflets equidistant, 60 cm to 90 cm long, narrow, tapering, linear, lanceolate, coriaceous, flaccid; petioles stout, 90 cm to 150 cm long.

Spadix is 1·2 m to 1·8 m long, stout, erect, straw or orange coloured, androgynous, simply branched; branches (spikes) bear one or more female flowers, often between two male flowers towards their bases, and several males above; spathes 2, outer short, inner 60 cm to 90 cm long, oblong, hard, splitting lengthwise. The palm is monoecious with female flowers relatively few. Male flowers are numerous, small, unsymmetric, sweet scented; sepals small, valvate; petals about 6·4 mm long, oblong, acute, valvate; stamens 6, filaments sabulate, anthers linear, erect; pistillode minute. Female flowers are larger and fewer than the male, about 2·5 cm long, globose, bracteolate, perianth greatly accrescent, round, concave, imbricate. Petals are shorter than the sepals, convolute with imbricate tips; disc annular. Ovary is tri-carpic usually one ovuled, sub-basilar.

Fruit is a large, 20 cm to 30 cm long, trigonously obovoid or sub-globose, three sided, one-seeded drupe. The outer layers of the pericarp are thick and fibrous. The inner layer (endocarp or shell) is very hard, horny or stony with three basal pores or marks representing the remains of 3 carpels or the loci of the ovary, two of which have become obliterated. Under one of these lies the embryo. The thin testa cohering to the endocarp is lined with white albuminous endosperm (meat) enclosing a large cavity, partially filled with a sweet fluid.

THE ROOT

The coconut palm has an adventitious root system as typical of a monocot, i.e., it produces numerous uniformly thick roots from the base of the stem almost throughout its life. The roots radiate from all the sides and are generally disposed to keep the direction in which they start. These are the main roots. The total number of such roots in a tree depends upon its age and the environment. On the poor sandy soils of the Malabar Coast (India), according to Sampson (1923), they may vary from 1,500 to 2,500 in a tree aged about 25 years and he has also recorded 3,620 roots in a 60 to 70-year-old tree. Patel (1938) counted 6,855 roots in a 45-year-old palm in the red sandy loam soil of the West Coast of India, while Copeland (1931) states that in the Philippines, the number of roots counted on a bole usually varies from 4,000 to 7,000. Although numbers much higher than these are rare, it is interesting to note that as many as 11,360 roots have been counted on a bole of a very old tree at the Central Coconut Research Station, Kayangulam (loose sandy soil). The main roots measure 6 m in length on an average and in rare instances they may grow even up to 25 m. They are usually of uniform thickness of about 8 mm in diameter. Under certain environments (when mechanically or otherwise injured) they produce one or more branches which are almost as thick as the original roots. The main roots and the branch-roots, produce numerous rootlets, which in turn branch freely again and again. The main roots and branch-roots are generally long-lived, while the rootlets, particularly the tertiaries and their branches, are short-lived. However, the latter are replaced often during favourable conditions. Coconut roots are also provided with numerous lenticel-like outgrowths or ventilators which may be called ' breathing organs ', ' breathing roots ' or ' pneumatophores ', which help in the exchange of gases. These white, pointed breathing roots are seen mostly on the main roots and sparsely on the rootlets.

Normally, roots are not formed very much above the bole region even when buried in the ground. But, when the tree is old or when raised on water-logged areas, the roots commence to die from the apex upwards. When this stage is reached, the tree, in order to maintain itself, commences to form new roots above the normal root-producing zone at the base of the stem. These are termed aerial roots (Menon *et al.*, 1955).

The first root

When a seed nut is sown, it starts germinating and in about six weeks, the upper part of the embryo just emerges out of the eye. This grows into a small white fleshy body which embodies the plumule and the first root. The top of this fleshy body is flat and almost circular. The primordium of the first root lies in its centre. One side of this body grows rapidly and forms the beak or the first rudimentary leaf. Two weeks after germination, the first root would have grown about one centimeter.

Sampson (1923) was of opinion that the first root originates from the axil of one of the basal scale leaves of the young plant. But, according to Davis and Anandan (1957), the first root starts from the pro-stem, and not from the axil of any leaf (Fig. **5**). After about six more weeks, the shoot is visible above the husk at the stalk-end, and by this time the seedling would have produced three roots, the oldest measuring about 20 cm in length with a number of rootlets (Fig. **6**). Subsequent roots originate generally from the close proximity of the first root. The second root is formed not later than ten days after the first. The later formed roots as observed by Sampson, originate from the axils of the rudimentary leaves.

In about a week after the formation of the first root, i.e., when it has grown to a length of 4 cm to 6 cm it produces one or two rootlets. Rootlets of various sizes are formed in quick succession. Breathing roots are also formed on the first root.

A majority of the early formed roots which have the definite tendency to penetrate the soil vertically downwards is comparatively thinner in size than the later formed ones. This size is maintained practically throughout their life. The longevity of the first roots has not been studied ; however, they have been observed to live up to eight years under healthy conditions. In a forty-year-old tree, the root system of which was examined, not even one dead root could be seen showing thereby that the first formed roots might live for considerably longer periods.

Bole

Roots are localised generally at the lowermost region of the stem which has been termed the ' bole '. Bain (1937) designated this as " Boll ". This portion is invariably buried in the soil. As growth progresses, i.e., when a large number of leaves and roots are formed, the stem grows upwards in height and its size uniformly increases and acquires the shape of an inverted cone. The diameter of the bole as well as the slant height of the conical portion varies with individual trees, localities and depth of planting. The slant height is observed to be between 20 cm and 30 cm. In some, the apex of the cone has a flattened appearance.

When the seedling is three to four years old, the growth of the conical portion of the bole is completed and the stem grows almost cylindrical thereafter.

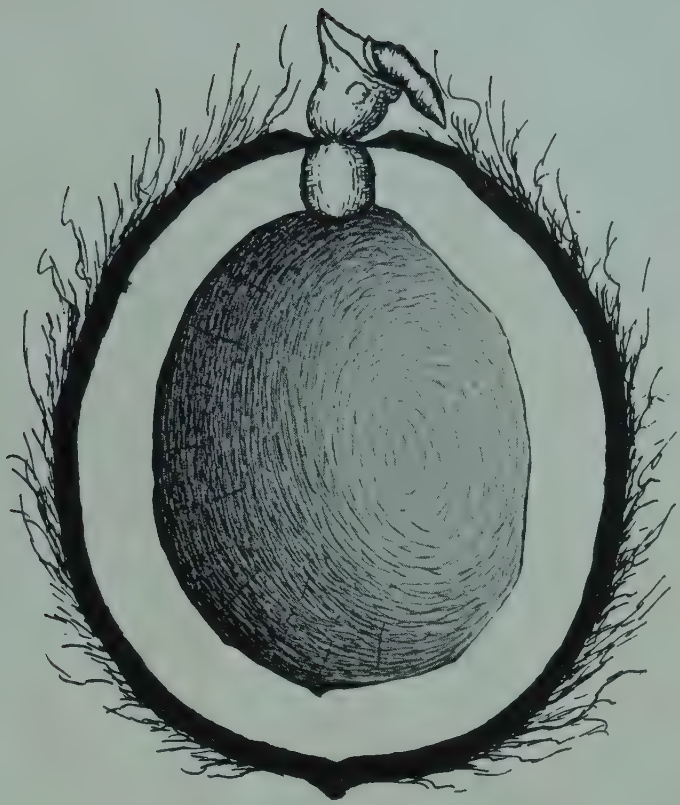

Fig. 5. First root starting from the ' pro-stem '

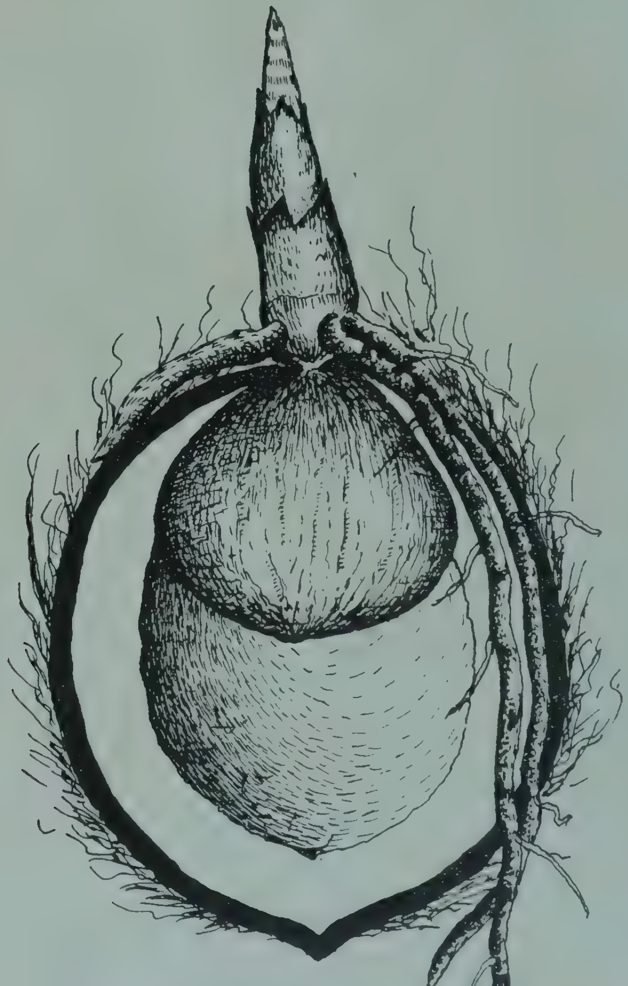

Fig. 6. Stage in growth of roots when the shoot just emerges out of the husk

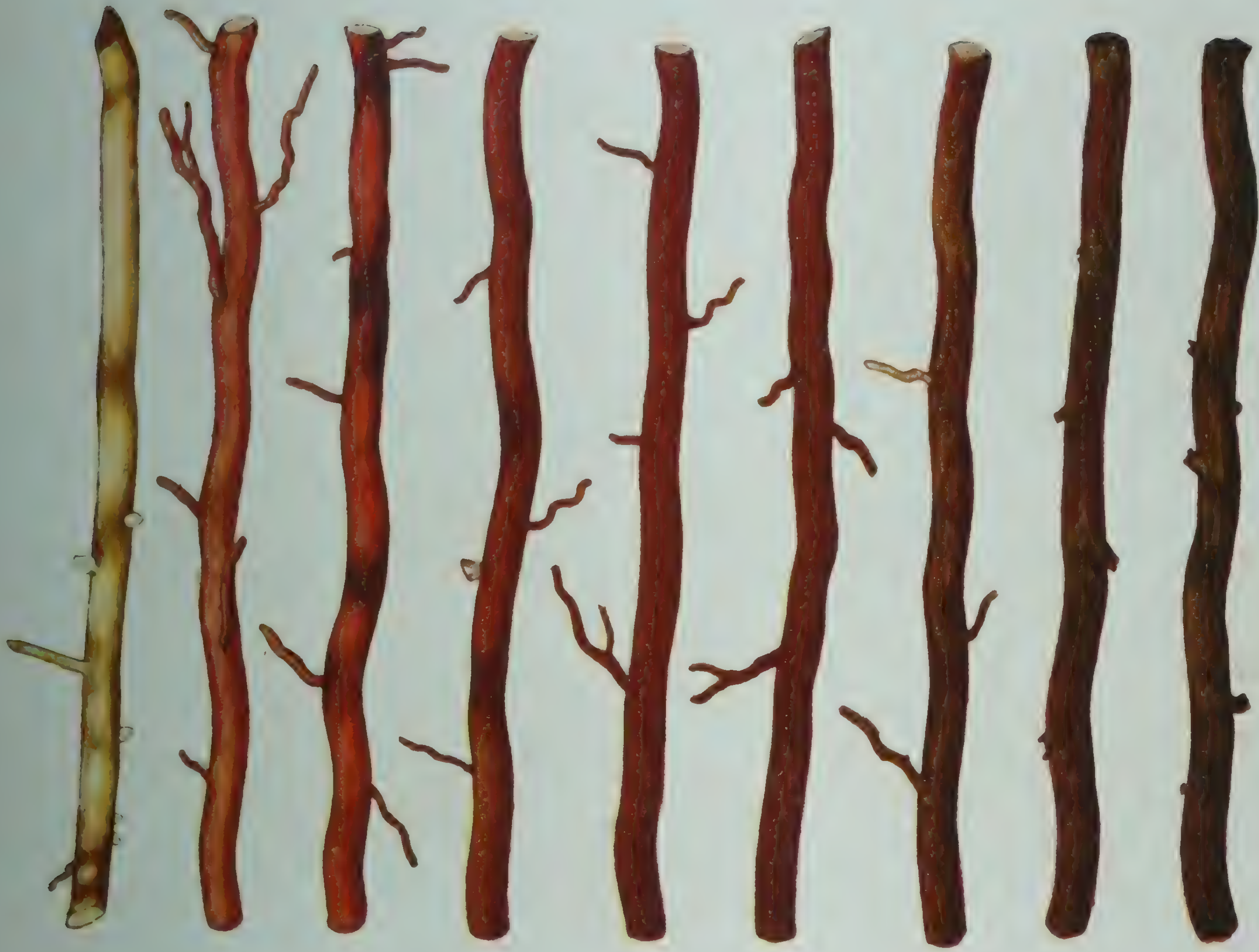

Fig. 7. Age and colour of roots

In deep planted trees the bole portion will be 80 cm to 100 cm in height, but in surface planted trees it will be only 30 cm or less. In the latter case roots are also formed from the aerial portion of it in the immediate proximity of the ground. Surface planted trees have a swollen base including the underground portion. Usually the length of the swollen part does not differ very much from the length of the root-bearing portion of the stem in deep planted adult trees. This indicates the presence of a definite portion in the stem for root production under normal conditions. Though the bole is the normal root-producing region, any other part of the stem can also produce roots under certain conditions. In the bole area itself the concentration of roots has been reported to vary in its different parts (Sampson, 1923).

Life of the bole

The bole does not continue to be active till the tree normally dies. In the tall variety of coconut which under normal environment lives upto 80 to 100 years, the bole starts decaying from the apex and the decay extends upwards. An examination of the boles of fourteen healthy trees, some of which were above fifty years in age, growing in well drained sandy loam soil showed that the boles would live up to fifty years and more, unless subjected to severe injury, mechanical or otherwise, causing premature decay. A tree usually continues to live for about 15 to 20 years after its bole starts decaying. In rare cases where the entire original bole had decayed, trees have been observed to continue to live with the help of a few aerial roots functioning as underground roots after their penetration into the soil.

Main roots

As Sampson says, the main roots are the arteries through which most of the water and mineral nutrients of the plant are taken in. The root of the coconut is protected at its tip by a thimble-shaped structure called the ' root cap '. The length of the cap is somewhat greater than the diameter of the root. Immediately behind the cap, is the young part of the root, known as the ' absorbing zone ', which is covered over by very delicate epidermis through which the root absorbs water and mineral food dissolved in it. The rest of the root is covered over by a thick, hard, impervious layer known as the hypodermis which enables it to withstand drought under normal conditions.

Spread of main roots

Vertical penetration. The length as well as spread of roots is largely controlled by the nature of the tree, the condition of soil moisture, the culture it receives and the nature of soil. Sampson states that there are also great variations in what may be termed the ' root habit ' of the coconut palm. No detailed study has been made of the relative root habits of different varieties or types of coconut.

As already mentioned, a substantial number of the early formed roots of the seedling go vertically as far down as the nature of the soil and level of water table would permit. In a few one-year-old seedlings, roots were found to have penetrated 4·3 metres below ground level. In a 60-year-old tree growing in deep sandy loam with deep water table, three vertical roots were found to have reached the water table, about six metres below. Subsequent roots spread horizontally. The branch roots of these may go down vertically or obliquely depending upon the depth of soil or water table. Coconut roots cannot indefinitely grow into water or stand continuous water stagnation. If the latter condition prevails, the submerged portions of the root get decayed. When the water table goes down subsequently these roots again branch freely and continue their growth, producing large number of rootlets. Temporary stagnation does no harm to them.

In low-lying backwater areas like Kuttanad in Kerala, where the coconut is grown on made-up soils, the water table remains always high throughout the year, never going lower than a metre from the surface. This condition considerably restricts the depth to which the roots can penetrate even in favourable seasons. The narrow width of the bunds also limits their lateral spread. The majority of the vertical roots are well under water for a considerable time, with the result that their tips rot and branch-roots are produced from the living portions. Most of these roots die away after a few years and fresh roots are formed from the bole to make good the casualties. A very large number of roots spread laterally and produce branch-roots and rootlets in the limited space available so much so in the course of a few years the soil is inter-woven by a matting of roots. These trees produce ' aerial roots ' much earlier than the surface planted trees in other soil types.

Lateral spread. Though roots are strongly disposed to keep to the direction they start in, a good many of them are seen to change it following the line of least resistance. Each root follows its own course, sometimes coming close to the surface and sometimes going deep. About 25 per cent of the roots in a five-year-old palm studied were found to go down, while the majority of subsequent roots spread horizontally or slantingly.

The spread of roots in one quadrant of a 40-year-old healthy tree growing in well-drained sandy soil was studied in detail. This tree had a very wide spread of roots. The maximum length of a single root was 22 m, its tip lying 20 m away from the tree and 2·58 m below the surface. The first 19 m of this root had a practically horizontal spread within 60 cm to 75 cm below ground level and the remaining portion penetrated to a further depth of about 2 m. It was in a growing condition at the time of observation.

All the roots were traced to their points of origin on the bole and their length, depth of spread and their condition were recorded.

Table 5 gives the distribution of roots according to their total length and depth of penetration.

Table 5.—Percentage distribution of roots according to their length and depth

Length of root (in metres)	Depth of root tip below ground level (in metres)																Total
	0·3	0·6	0·9	1·2	1·5	1·8	2·1	2·4	2·7	3·0	3·3	3·6	3·9	4·2	4·5	4·8 and below upto water	
1·5	0·53	0·70	2·33	0·72	2·14	–	–	–	–	–	–	–	–	–	–	–	6·42
3·0	–	0·18	0·18	3·22	6·26	1·61	0·18	0·18	–	–	–	–	–	–	–	–	11·61
4·5	–	–	–	0·70	0·72	0·55	0·18	0·18	–	–	–	–	0·18	0·37	–	–	2·88
6·0	–	0·54	0·55	0·56	0·35	2·54	2·19	1·28	–	–	0·18	0·42	1·00	2·11	2·54	18·01	32·27
7·5	–	0·18	1·05	1·05	1·24	2·60	0·71	0·34	0·30	0·35	0·25	0·18	0·25	0·86	0·54	17·00	26·90
9·0	–	0·54	0·71	0·35	0·73	0·70	0·71	0·70	0·54	0·36	–	0·54	0·50	–	1·00	1·25	8·63
10·5	–	0·36	0·17	0·16	0·18	0·70	0·36	0·54	0·35	0·37	0·18	–	–	0·16	0·17	0·75	4·45
12·0	–	0·16	0·18	0·20	0·15	0·21	0·36	0·18	0·54	0·18	–	–	–	–	–	–	2·16
13·5	–	0·16	0·53	0·55	0·18	0·56	0·35	0·36	–	–	–	–	–	–	–	–	2·71
15·0	–	0·18	0·18	–	0·18	–	–	–	0·16	0·20	–	0·14	–	0·04	–	0·18	1·26
16·5	–	–	–	0·18	–	–	–	–	0·35	–	–	–	–	–	–	–	0·53
18·0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
21·0-22·5 ..	–	–	–	–	–	–	–	–	0·18	–	–	–	–	–	–	–	0·18
Total	0·53	3·0	5·90	7·49	12·13	9·47	5·04	3·76	2·42	1·46	0·61	1·28	1·93	3·54	4·25	37·19	100·00

It is seen that about 50 per cent of the roots of this middle aged tree penetrate deeper than 3 m into the soil and about 38 per cent have gone into the permanent water table, i.e., 5 m to 5·5 m. The surface feeders are concentrated within the first 1·5 m layer of the soil.

In loose sandy soils large number of roots spread laterally not deeper than 1·3 m from ground level and a considerable number consisting of the majority of early formed roots and a good portion of the subsequently formed ones go either directly or slantingly down so as to reach the underground water or the layer of soil with substantial moisture content. The main roots in the superficial layer of soil, particularly those within the first one metre, produce large numbers of rootlets which grow in all directions to absorb plant food. The main roots in this and in the lower layer spread almost horizontally and produce rootlets. Some of these subsequently grow thicker, assume almost the same thickness as the main root or the branch root and go vertically down as deep as the permanent water table. Very large number of such roots starting as ordinary rootlets and growing bigger in size as they go down are met with.

AGE AND COLOUR OF ROOTS

The exact age of a root cannot be assessed with much accuracy, except when they are of recent origin. All that can be done is to classify them into broad age groups like fresh, young, middle aged, old and very old. These classifications are possible because of the definite gradations in the colour of their outer covering as they advance in age. An old but growing root does not have the same colour from its start right up to the tip. The growing portion is usually whitish in colour though there is variation due to inherent character. This particular portion changes into cream as the root puts forth further growth and then into orange, scarlet, red, brown and dark or dirty brown in the end. The change from one shade to another is generally gradual except when the outer layer hardens rapidly. Thus in fairly old and growing roots, all the above mentioned colour gradations may be seen. Therefore the age of a root is assessed with reference to its colour at its base (near the bole). An examination of roots of palms of different ages, 1, 2, 3, 4, 5, 6, 10, 25, 40, 45, 50 to 55 and 60 years was made. All the roots of a one-year-old seedling are either white or cream in colour. In 1 to 2 years they turn orange, then become scarlet and remain so for about a year. In 4 to 5 years they are red, increasing in intensity till they are about ten years old, afterwards they start becoming brown. Dark brown roots are met with in palms above 15 years old and the number in this group naturally increases as the age of the tree advances. It is thus possible to guess the age of a root up to a stage (Fig. **7**).

In trees where the production of main roots has not stopped, roots in all the above mentioned colour categories are met with. The following table gives the percentage distribution of roots of various colour groups in trees of different ages:

Table 6.—Distribution of roots according to their colour

Colour	Age of trees in years							
	1	2	3	4	5	10	40	60–70
White and cream	100	82	60	48	35	15	4·4	6·0
Orange		18	32	33	32	8	5·5	7·8
Scarlet			8	16	20	8	6·5	–
Red				3	13	21	6·0	9·1
Deep red						48	7·6	–
Brown							22·0	9·9
Dark brown							48·0	12·9
Dirty brown								54·3 (*a*)

(*a*) dead roots.

RELATIONSHIP BETWEEN THE GERMINATION OF NUTS AND THE ROOTS

The number of roots per seedling and the time taken for germination after planting the nuts in the nursery were correlated for a group of 200 one-year-old seedlings of the tall variety. A negative correlation amounting to —0·290±0·044 was obtained (Patel, 1938). This value, though low, is significant and indicates that early germinated seedlings have generally greater number of roots. Since early germinated seedlings start the photosynthetic activity earlier than the later germinated seedlings, it is to be expected that root development will be more vigorous in the former group. There is a similar relationship between the weight and the total length of roots to the time taken for germination. But the value of *r* (coefficient of correlation) is less and is not significant. An analysis of the root measurements of one-year-old seedlings recorded during 1921, confirms the above observation. The seedlings are classified into four groups according to the time taken for germination and the average of the growth measurements, viz., (1) the number of roots, (2) the average length of a root, (3) the number of leaves, and (4) the height. These are tabulated below. The figures are the averages for a group of 50 seedlings making a total of 200 seedlings for the four groups. The differences either in the average length of the root or in the average number of roots are not very wide except for the group of seedlings germinating late.

Table 7.—Germination of nuts and root characters

Germination	Period of germination	Average No. of roots	Average length of roots (cm)	Average No. of leaves	Average height of seedling (cm)
Early	10th Sep. 1920 to 15th Oct. 1920	10·8	76·2	8·2	119·3
Medium	16th Oct. 1920 to 21st Nov. 1920	10·6	71·1	7·8	114·2
Medium late ..	22nd Nov. 1920 to 21st Dec. 1920	10·1	66·0	7·6	109·1
Late	22nd Dec. 1920 to 22nd May 1921	8·6	58·4	7·3	81·3

GROWTH RATE OF INDIVIDUAL ROOTS

In seedlings and in young palms roots grow rapidly and in quick succession unlike those of older trees. This condition is continued till an optimum number as well as an aggregate length is reached and maintained. The rate of growth in individual roots slows down beyond the third or fourth metre of their length in the horizontally spreading roots. This is evidenced from the absence of longer lengths of white tender portions beyond this length when compared to those in younger roots. The rate of growth may be controlled by the season, length of root, nature of soil, etc. There is every probability that the deep growing roots maintain a higher rate of growth in loose soils till they reach the water table. New roots are formed throughout the year in young trees, while in old trees these are usually developed from the beginning of the monsoon showers in May-June.

In very young germinating seedlings a root grows about 1 cm in a day; in a one-year-old seedling, a single root 427 cm long was noted among the deep going roots. The growth of four fresh roots each, in four five-year-old trees, in a low-lying area was recorded. These roots started development after the commencement of pre-monsoon rains in May 1956. The growth of each root was followed for four months at monthly intervals. The data are presented in the table below:

Table 8.—Growth of fresh roots

Serial No. of roots	Growth during months in cm				Total growth in four months
	1st	2nd	3rd	4th	
1.	12·5	23·0	11·5	9·0	56·0
2.	14·0	19·0	18·0	11·0	66·0
3.	9·5	15·8	17·0	8·0	50·3
4.	20·5	30·0	21·0	13·2	84·7
5.	15·5	15·5	14·0	12·0	57·0
6.	11·3	17·3	18·0	14·0	60·6
7.	8·0	11·2	7·0	5·0	31·7
8.	14·0	21·0	18·0	15·5	68·5
9.	18·5	29·0	22·0	14·0	73·5
10.	9·0	16·0	14·0	10·5	49·5
11.	7·5	15·5	17·0	11·0	51·0
12.	11·5	21·0	18·0	14·0	64·5
13.	19·0	30·0	25·0	24·0	98·0
14.	13·0	17·0	15·0	14·0	59·0
15.	18·0	21·0	30·0	18·0	77·0
16.	11·0	17·0	..	..	..

The roots in a one-eighth sector of the bole of a robust five-year-old palm were completely cut almost flush with the bole in the first week of May 1956. The excavation was filled up on 10th May 1956. This portion of the bole was again examined on 29th August 1956. It was observed that a large number of fresh roots developed from this area and some of them had grown as long as 1·39 m. The period of emergence of these roots from the bole was, however, not recorded.

In the course of experiments conducted to study the reaction of roots to pruning, roots of seedlings were seen to have put forth a maximum growth of 4·2 m in one year.

The study on this aspect has not been extended to grown-up trees. It is noted that fresh roots grow very fast in the early stage, i.e., first three months and thereafter growth slows down. The length of a root depends chiefly on environment.

Longevity

The longevity of a root (main root) depends on the sub-soil water level and the texture of the soil in which it grows. Needless to say it ultimately depends upon the life of the bole from which it originates. In well drained sandy soils, the tall variety of coconut lives up to 80 years or more. Shorter-lived trees also are sometimes met with in such soils. Underground boles of fourteen healthy trees, some of them estimated to be over 50 years of age were examined to study their condition and the condition of the roots particularly those in the lower region. In the majority of the trees, even the apex of the conical portions of the boles was in perfect condition. The roots at the lower-most ends of boles are expected to be as old as the trees themselves. This shows that the roots live for a very long time, even more than 50 years under suitable conditions. Again, the study of root system of trees in areas with water table as high as six feet below ground level has revealed that roots which go deep and get submerged under water for a month or two do not easily die away. They adapt themselves to the unfavourable situation and tide over it. However, if the adverse condition persists indefinitely, only that portion of the root lying in the stagnant water rots. Immediately after the situation improves, these roots produce branch-roots or rootlets or both.

Vertical roots in places having a hard pan behave in a peculiar manner. On reaching the hard layer, they become slender and/or flat, with a rugged surface in their attempt to penetrate the hard medium. Still, such specialised roots live for a long time. It has been observed that as roots progress in age, their hypodermis becomes stronger and the cortex hardens.

In the very old tree referred to earlier, only a small portion of the lower part of the bole had decayed. But it was noted that some of the roots emerging from the healthy portion of the bole were dead and not functioning. Many other roots from the same area had short lengths of healthy portions, their distal ends being dead. Most of these roots could be expected to be very many years old. There were many fresh rootlets on the basal ends of roots, each possessing numerous breathing roots. Even under ideal environments, roots in coconut do not live indefinitely. They are prone to natural decay.

Sampson observed in a 60 to 70-year-old tree that none of the roots in the top 38 cm of the bole was dead. Some of these roots must have been as old as 50 to 55 years. It is thus evident that roots can and do live for a long period.

Reserve roots

When a tree has a sufficient number of healthy roots to carry out its normal functions, the speed of production of fresh roots will slow down. Many of the trees irrespective of their age produce a few new roots during the most conducive seasons every year. In an adversity leading to the death or destruction of a large number of main roots, the tree might replenish the root system by producing a large number of rootlets and also by developing roots from the underground bole, although Sampson is of opinion that coconut has also a reserve of dormant roots. He estimated the total number of roots in six 25-year-old trees. They had produced about 2,000 roots on an average. He noted that there was hardly a dead root to be found in all those which had been produced during the life of each tree. He stated that this would not necessarily mean that all the roots on the tree were functioning normally and concluded that many of them were practically dormant roots which could take up active work when necessity arose. Any adverse situation which affects the functioning roots would naturally affect the dormant roots also. It is not, therefore, clear whether a reserve of dormant roots exists in coconut at all. Results of experiments conducted at the Central Coconut Research Station, Kayangulam suggest that most of the healthy-looking roots are capable of exuding root sap, thereby indicating their power of absorption and conduction.

In the 60 to 70-year-old tree, the root system of which was examined by Sampson, 54·3 per cent of the roots, all lying in the lower part of the decaying bole, were dead. There were 217 white roots produced from the upper part of the bole. Orange, red and brown roots were also seen in large numbers. So, new roots are produced when old or existing ones die from underground or aerial parts of the stem as the case may be. Ere long the new production either stops or becomes too meagre.

DAMAGE TO ROOTS

" Illuk ", a plant parasite. The roots of coconut have a hard sclerenchymatous protective covering, the hypodermis. In India, no plant parasite has been reported damaging the coconut root. In Ceylon, a grass weed, locally called " Illuk " (*Imperata cylindrica*) is reported doing much harm to the roots of coconut (Rajapakse, 1950, 1950a). A similar grass in Malaya called " Lalang " and in the Philippines a grass called " Cogon " are known to be equally harmful to coconuts. " Illuk " is a very hardy grass weed thriving on all types of soils. This weed is a great menace to young coconuts, as well as to some other economic crops in Ceylon. The root-destructive nature of the weed was first detected in Malaya.

" Illuk " spreads rapidly and profusely, forming a complicated system of matted masses of rootlets, connected by long runners of underground stem. The growing end of one of these stems has a sharp, unyielding, bayonet-like point. This sharp point will penetrate into the root and pass along the stele for one or two feet, emerging again later, when perhaps it may rise to the surface to produce a fresh head of grass. The underground stem swells and the coconut roots burst wide open. By this, water is let in, the tissues gradually rot and die. Thus many feet of root system are destroyed by a single penetration of this parasite. When the root penetration and destruction is general, the plant becomes progressively weaker and gradually tapers off and dies.

The root eating grub of cockchafer beetle (*Leucopholis coneophora* Burm.). The tender roots of coconut are eaten by the young larvae of a beetle (*Leucopholis coneophora* Burm.). The severity of damage due to this pest is seen in Mavelikara and Tiruvella taluks of Kerala (India). The young larvae are seen feeding generally on the growing regions of the rootlets eating away their tips. No doubt this stimulates the production of many more rootlets. But these are also destroyed by the larvae.

Termites (*Odontotermes obesus* Ramb.). Coconut seedlings as well as adult palms are damaged by termites. The fleshy parts, viz., collar, apple, kernel and roots are often eaten by the pest. Corbett (1932) was of the opinion that the workers of the common termite damaging coconut palm in Malaya start destroying the roots and leave the bole barren. In India, however, root destruction by termites is not a serious problem. Heavy damage due to ant-hills has been reported in Ceylon (Ambrose, 1951). The tender roots that penetrate into the cavities of ant-hills during wet weather conditions meet with premature death as the conditions prevailing in the tunnels are greatly uncongenial for proper growth. Even mature roots when enveloped by termitarium of hard earth are severely damaged. It is known that coconut root has great longitudinal tensile strength because of the hard central core (stele) and the sclerenchymatous covering (hypodermis). However, it has no lateral resistance because of the presence of a thick cortex of soft tissues between the hard stele and hypodermis. Further, the hypodermis is brittle in nature. During dry seasons, the multi-chambered walls of the ant-hills engulfing the roots harden and the contraction thereby caused exerts great pressure laterally on the roots, thus causing death to most of them.

Water-logging, disease, etc. Though coconut roots have some adaptations like those of the hydrophytes, yet they are unable to live submerged in water indefinitely. During severe monsoons the entire root system of most of the trees in low areas gets covered by floods. When the root normally reaches the permanent water table it slows down growth and the tip gets rotten. Rotting of the root tip gets accelerated if the subsoil water is acidic or alkaline.

Diseases like the ' wilt disease ', ' root-rot ', etc., are also responsible for the death of roots in coconut.

As has been seen, most of the main roots of trees growing on sandy soil and receiving good rains are distributed horizontally a few feet below the soil surface. Due to prolonged drought, some of the upper roots may wilt permanently. Drought affects the rootlets earlier than the main roots.

Cultural operations such as deep ploughing, forking, bund-making, making deep trenches, etc., are responsible for root destruction to some extent. But invariably such cut roots produce branches soon and make good the loss.

ABSORBING POWER OF MAIN ROOTS

An adult tree has as many as 2 to 3 thousand living main roots. Sampson says " In themselves they are of little use in absorbing plant food from the soil, since only a small area immediately behind the growing end is capable of doing this ". However, the absorbing power of the main roots cannot be ignored easily because most of the roots possess long absorbing region towards their tips. During the rainy season new roots are formed and also old roots usually grow afresh. The absorbing surface of a single main root will equal that of a large number of rootlets put together. Rootlets do not have a longer absorbing region than the main roots. In fact they have a very short region. Therefore, the absorbing region of the entire number of main roots is really considerable. In a young growing main root, a minimum of 5 cm length of absorbing region is available. In vigorously growing fresh roots the white region comprising the epidermis and the hypodermis was observed over a length of even 120 cm. On an average, a single main root was observed to absorb and pump up about 2 cc of water in 24 hours. Thus a tree having about 2,500 functioning main roots will be able to absorb about 5,000 cc of water every day.

ROOTLETS

The main roots produce secondary roots called the rootlets under all conditions. Such rootlets branch again and again and branching up to the fifth order may easily be made out. The absorbing region of the main root is scattered in different layers of soil, and these roots can exploit only very limited space. Rootlets are, therefore, freely produced mostly in the upper fertile layer of soil and grow in all directions. They are concentrated around the stem within a radius of 150 cm to 180 cm where manure is generally applied. Also, when the main roots happen to come across decaying organic matter, rootlets are produced in abundance.

Rootlets, especially those of the higher order are short-lived, their life being much shorter in the top layers of loose sandy soil. They are more flimsy and become brittle under dry conditions due to the hardening of their cortex. They radiate almost at right angles from all sides of the main root.

As has already been mentioned, production of the first rootlet starts within a week after the formation of the first root. New rootlets have also been observed to emerge through holes of dead rootlets. The number of rootlets existing on a unit length of a main root depends on many factors, viz., the texture of the soil, its fertility, the moisture content in summer and the intercultural operations the soil receives. In loose sandy loam soil of medium fertility, it has been found as a result of examination of roots of thirty adult trees, that a main root in its prime of life has as many as one living rootlet for every two cm of its length. The frequency of rootlets is progressively less in deeper layers of the soil. An adult tree may have 2,500 to 3,000 living main roots. Some of them have branches also. The magnitude of the net work of roots and rootlets can well be imagined.

Thickness of rootlets

Like the main roots, wide variations exist in the thickness of rootlets of a particular order, between roots of the same tree and between trees. The following table gives the average thickness of rootlets of a set of trees observed.

Table 9.—Average thickness of rootlets of 1st, 2nd and 3rd order of a set of trees (tall variety)

Serial Number	Order of roots						Estimated age of trees
	1st order		2nd order		3rd order		
	Thickness of roots (mm)	Range	Thickness of roots (mm)	Range	Thickness of roots (mm)	Range	
1.	3·6	3·2–4·3	1·5	1·2–2·0	0·6	0·4–1·0	10 years
2.	2·0	1·1–3·8	1·7	0·8–2·0	0·9	0·5–1·7	25 ,,
3.	1·8	1·1–3·1	1·6	1·0–2·5	0·9	0·4–1·3	50 ,,
4.	2·5	1·1–4·5	2·0	0·9–2·9	1·1	0·8–2·0	50 ,,
5.	3·1	3·4–6·0	2·6	1·9–3·1	0·9	0·6–1·5	45 ,,
6.	3·5	2·9–4·8	2·0	1·1–2·6	1·5	0·9–2·1	35 ,,
7.	2·7	1·5–3·9	1·3	0·8–2·1	0·6	0·5–0·9	45 ,,
8.	2·6	1·3–3·7	1·6	1·0–2·1	0·8	0·5–1·0	50 ,,
9.	1·7	1·1–3·1	0·8	0·6–1·3	0·5	0·3–0·9	45 ,,
10.	2·4	1·2–3·6	1·6	0·9–2·4	0·6	0·3–0·7	45 ,,
11.	0·9	0·6–1·6	0·6	0·4–1·0	–	–	1–2 ,,
12.	0·9	0·5–1·5	0·7	0·5–0·9	–	–	1–2 ,,

The figures are the average of 100 measurements of individual rootlets of the first and second order and of 25 measurements of the third order. In seedlings, roots and rootlets are much thinner. The mean thickness of roots and rootlets of 100 one-year-old seedlings is 4·6 mm and 0·9 mm respectively.

THE EFFECT OF PRUNING ROOTS OF ADULT PALMS

This study was conducted at the Central Coconut Research Station, Kayangulam. A large number of the main roots of 24 adult palms (45 to 50 years) were pruned at different distances from the bole and at different depths from the surface. The distance ranged from 1 m to 6 m and depth up to 2 m from the soil surface. The main roots were pruned and labels were tied to their ends to enable tracing them later on. The excavations were covered and the roots examined after one year. Most of the roots produced one or two branch roots each. The dead ones were seen more towards deeper layers.

SURFACE MATTING OF ROOTS

Ambrose (1951 a) gives a brief account of the surface matting of coconut roots which he termed " bissa ". These roots according to him are yellow, desiccated and unhealthy and form a circle several feet in diameter round the base of the palm. In Ceylon, 'bissa' is generally found in " regions where the land is water-logged during a large part of the year, when the watertable is high and in loose, sandy areas with a basin or pan of coral 'rock', clay or cabook. In both the conditions, there is generally a stagnant or immobile water condition ". The palm under such circumstances, in its struggle for existence, will develop most of its roots towards the upper layer which forms a matting.

In India, surface matting of roots is not very common. However, in certain water-logged areas, numerous roots which start from the aerial stem in close proximity of the bole form a reticulate matting resembling the ' bissa ', described above. Also in gardens, where cultural operations are not carried out for a long time, there is a tendency for the formation of surface matting of roots. The formation of root matting generally denotes poor nutritive status of the soil and lack of intercultivation. Regular cultural operations, adequate manuring and providing proper drainage wherever necessary will prevent the formation of root-matting.

SUCKING POWER OF ROOTS

While the unsevered root has absorptive power, the cut end of a root (in contact with the stem) has a much greater power of sucking. This power of suction is due to the transpiration pull operating on the leaves. This has been taken advantage of by Davis *et al.* (1954), for liquid injection in coconut and similar palms. Sucking power of different roots varies. Different portions of the root were also tested for their efficacy in sucking.

It was observed that the cut ends of fully mature functioning roots absorb the maximum quantity and the root with unsevered tip has the least absorption.

Utilising the pumping and sucking power of roots, Davis (Nagaraj *et al.*, 1954) had devised a new method for virus transmission in palms by sap transfusion. By this method the sap of one tree could be pumped into another through root connections.

STRUCTURE OF THE ROOT

The main root and the rootlets have almost similar internal structure with the main difference that the tissues of the rootlets are much smaller and less defined. Also the number of the conducting tissues, especially the xylem vessels, is lesser in rootlets.

Root tip

The tip of the root carries the root cap and the meristem called calyptrogen responsible for the formation of root cap is also located there. The root cap consisting of dead tissue, 8–26 cells thick covers the tender portion of the root. Due to the rapid growth of the root, the root cap sheath gets detached from the active meristem and this sheath may be seen covering the root at various places. This is very prominently seen on the rapidly growing roots and branching rootlets. Again it is prominent on aerial roots. The growing root tip just behind the root cap does not possess any clearly differentiated tissues. Apart from the epidermis, the entire region has almost uniform meristematic cells which get differentiated into the various tissues later on.

A little length from the root cap in a growing root is the absorbing region, because most of the water and salt requirements of the tree is absorbed by this region. This function in most other plants is performed by the root-hair region. It may be remembered that coconut roots have no root hairs at all.

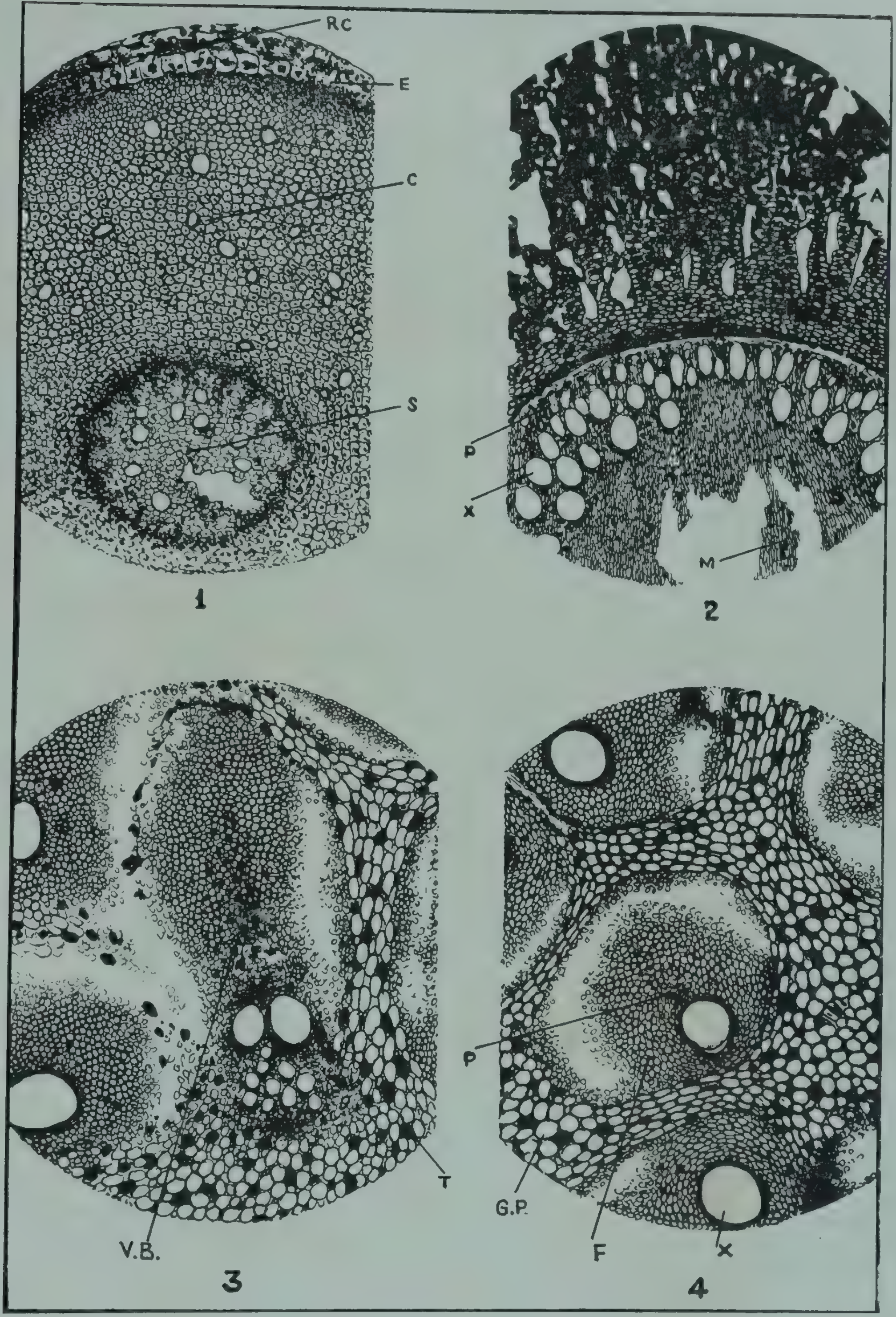

Fig. 8. **Structure of the root (1 and 2). Structure of the stem (3 and 4) (After Patel, 1938).**

1 C. S. of young root below the growing point; stele S; cortex C; epidermis E; tissue from root cap R.C.

2 C. S. of old root; xylem (meta) X; protoxylem P; band of sclerenchyma S; pith M; aerenchyma of cortex A.

3 C. S. of old stem; vascular bundle with many xylem vessels V. B; tannin cell T.

4 C. S. of old stem; single xylem vessel X; phloem P; fibrous sheath F; ground parenchyma G.P.

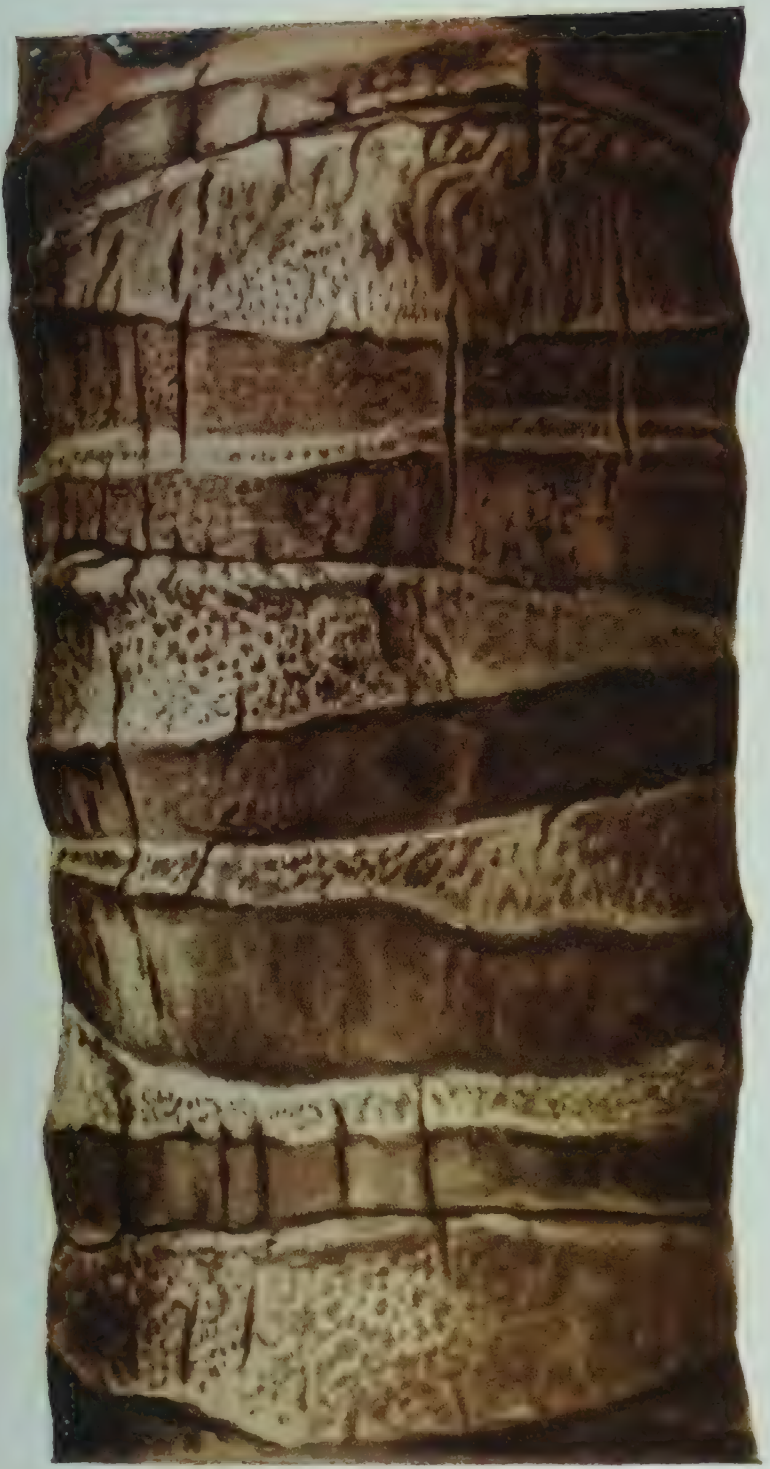

Fig. 9. Leaf scars on a stem
(After Sampson, 1923. *Kind courtesy:*
Staples Press Ltd., London)

Three distinct regions are recognised in a cross-section through the absorbing region, viz., (1) the outermost layer, the epidermis consisting of a single row of thin-walled cells, (2) the innermost central cylinder, the stele which occupies about one-fifth the diameter of the root, and (3) the thick cortical region located between the epidermis and the stele. (Fig. *8:1*).

The individual cells of the epidermis are much bigger than most of the cells of the hypo-endodermal layers. These epidermal cells though devoid of root hairs constitute the main absorbing tissue. However, they are short lived; they wither away as soon as the hypodermis (exodermis) attains an impervious sclerenchymatous condition. The function of absorption ceases at this stage. An interesting feature of these epidermal cells is the rare occurrence of two to four nuclei in many of them. The solid and liquid endosperm are also reported to be coenocytic in nature by Dutt (1953) and Cutter and Freeman (1954). Recently Nutman and Roberts (1955) have also observed multi-nucleate condition in some tissues of diseased palms and this made them suspect the ' Unknown disease ' of coconut palms in Jamaica to be of a virus origin, the multi-nucleate condition being attributed to the result of the virus. It may be mentioned that the other cells of the cortex and stele are only multi-nucleolate and never multi-nucleate.

The stele is the most important part of a root which comprises the conducting tissues. The stele is bordered by a single layer of living cells towards the periphery called the pericycle. It is from this layer that rootlets and breathing roots are produced. The initials of the rootlets are often formed soon after the pericycle is developed. The pericycle is capable of secondary activity even many years after its formation as evidenced by the development of fresh rootlets from very old roots. Enclosed by the pericycle and lying close to it are 30–55 radially arranged groups of small dividing cells called the procambial strands. The cambial activity of the stele is at this stage restricted to the meristematic cells within the procambial strands. The number of these procambial strands is considerably less in rootlets depending upon the size of the rootlet. These strands differentiate into the xylem and phloem; the xylem alternates with the phloem as typical of a root. The development of the xylem which is continuous with the protoxylem or the first-formed xylem is centripetal and the vessels are conspicuous though the thickening occurs at a later stage. Often two or more strands of xylem coalesce to form a bigger vessel. Ultimately an adult root may have about 25 large meta-xylem vessels. The phloem is very inconspicuous compared to the xylem. The companion cells of the sieve-tubes of the phloem are hardly distinguishable. The ground tissues surrounding the bundles are thin-walled, to start with. However, they soon develop into thick-walled sclerenchymatous bundle-sheath which adds to the tensile strength of the stele. In the centre of the stele there is a narrow pith consisting of living cells. Usually this tissue disintegrates in older roots. In between every two rows of xylem and phloem, there is a narrow ray of cells usually of two rows and much compressed by the developing xylem and phloem. The ray connects the inner ground tissue bordering the central hollow with the pericycle.

The cortex covers a major portion of the root. This may be roughly divided into the hypodermis or exodermis consisting of several layers just beneath the epidermis; the endodermis or the innermost single row of prominent cells and the mesodermis consisting of large-sized and loose parenchyma enclosing many air chambers. In the early stages, the aerenchyma is not prominent. But as the root assumes its maximum size, the cortical parenchyma, not being able to increase in size to keep up with this expansion of the root, detaches itself in strands or groups of cells. Air spaces are prominent in the mesodermis. The cells of mesodermis are bigger than those of the hypodermis. A number of broad empty cells are also noticed in the cortex, the function of which is not known. Apart from that, a good number of tannin cells are also seen in the cortex. The endodermis is a single row of small cells. This layer is clear even at an older stage. The inner wall is more thickened than the lateral ones and the outer wall is thin. There are just a few thin-walled passage cells occurring here and there. The hypodermis is made up of small thin-walled cells. But they soon get thickened and the epidermis stops functioning. It is this layer of cortex which protects the vital stele by its thick and rather pliable covering. The young root-branches pierce through the cortical tissues and in their early stage get protected by the cortex. Further, because of the continuous channel of aerenchyma present in the cortex, the root tip is able to have contact with the atmosphere even when it is submerged in water.

In a very old root (Fig. *8:2*) some further changes are noticed. As has been stated, the epidermis completely peels off and the position of this layer may be recognised by the irregular surface seen on the hard hypodermis. The hypodermis develops a red or dark red colour due to the dark pigment present on its upper layer. This hypodermis which becomes very prominent is made up of numerous layers of sclerenchymatous cells. Due to constant deposition of lignin and other protoplasmic materials on the cell walls this layer becomes a hard dead tissue impervious to water and even to air. Under droughty conditions, the process of thickening of the hypodermis extends almost to the very tip of the root. When a root is pressed, the hard hypodermis cracks and it can also be peeled off the thin cortical tissues. When some roots estimated to be more than one hundred years old and obtained from very old palms were examined, it was seen that almost the entire cortex was woody. The spongy cortex was completely transformed into sclerenchyma due to constant deposition of lignin and the aerenchyma of the cortex was almost completely filled up. Each row of xylem vessels alternates with a much smaller group of phloem. The bigger vessels are towards the centre of the roots and the smaller ones including the protoxylem are towards the periphery of the stele. The big vessels have thinner walls than the smaller ones; the latter are the older of the two. Xylem vessels measuring even 0·5 mm × 0·3 mm are not uncommon. The ground tissues which surround the bundles become more and more sclerotic and serve as a continuous bundle sheath. The pith in the centre of an old root invariably disintegrates.

THE STEM

When the bole reaches the full stage of its development, the stem becomes visible. The thickness of the stem generally depends upon the vigour of the tree, hereditary variation and soil conditions. In the initial years of growth of the tree the stem gradually increases in thickness and this thickness is maintained throughout. Growth of the stem may, however, become thinner as the tree gets older or meets with unfavourable conditions. The unevenness thus produced, though slight, persists and this is a visual record of the vicissitudes through which the palm has passed. The stem of the coconut grows erect under normal conditions. But trees on the margins of the plantations often lean away towards light. In places where winds often prevail, the trees will lean along the direction of the wind (Davis, 1956).

Any injury caused to the stem remains as the tissues of the stem have no capacity to repair the injury because of the absence of meristematic activity. It can, however, withstand considerable amount of damage due to the presence of fibrous tissues in the trunk. These strands are generally much closer together towards the middle of the tree enabling it to withstand considerable lateral strain particularly in times of severe winds and gales.

The coconut tree has only one growing point, the bud. If this bud is killed, the tree dies. The bud produces a succession of leaves. When the leaves grow old they are shed, leaving a rough pitted scar on the trunk which encircles the whole stem. From the counts of these scars the age of the trees can be approximately determined, as roughly 12 to 14 such successive scars left on the tree correspond to a year of growth of the tree. It is also possible to gauge the vigour of the tree from these scars. In a bearing tree the scars left by the inflorescence stalk (peduncle) may be seen on the stem in the middle above the widest portion of the leaf scar. The interspace between successive leaf scars may serve as an index of the bearing capacity of the tree or the environment under which it is grown (Fig. *9*).

Variation in the length and girth of the stem

The stem grows at a relatively rapid rate in the earlier years till the palm commences to bear. The rate of growth remains somewhat steady thereafter till the onset of senility when it begins to decline. The length of stem varies with variety, climatic and soil conditions and the attention bestowed to cultivation and manuring. The dwarf variety has a much shorter stem than the tall variety. According to Patel (1938) cultivation and manuring and better soil conditions favour the production of taller stems. Close planting is also reported to favour taller stems.

The girth of the stem is also similarly influenced by variety, fertility and moisture condition of the soil and its management. Observations made on the exotic palms growing at the Central Coconut Research Station, Kasaragod, show that the forms Philippines, Andaman Giant, etc., possess stems of larger girth. The girth of the stem does not appreciably change with the age, when once it has reached the maximum size.

The structure of the stem

The stem of the coconut is an erect, unbranched, stout cylinder derived from one terminal growing point, which is situated at the very top of the trunk, and is a minute protuberance nearly ½ mm × ½ mm in size, enveloped by leaves in varying stages of development and derived from it (Fig. ***10*** : *7* & ***11*** : *12*). The growing point consists of a mass of minute cells filled with dense cytoplasm and contains large nuclei. The nuclei are invariably multi-nucleolate. The number of nucleoli is four to ten. The mass of actively

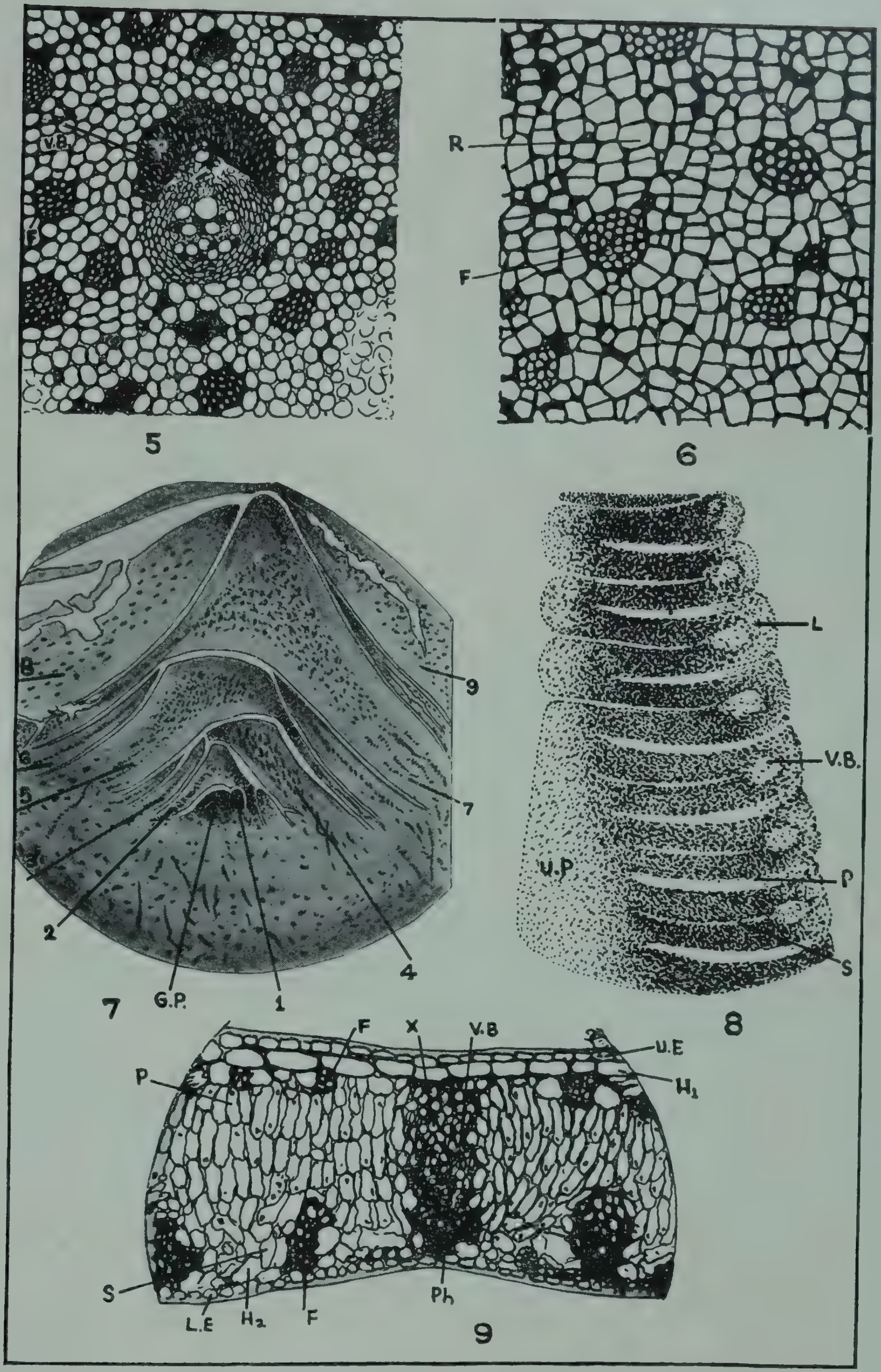

Fig. 10. Structure of periphery of old stem and structure of leaf (After Patel, 1938)

5 *C. S. of inner part of periphery of old stem; vascular bundle V.B; isolated group of fibres F.*

6 *C. S. of outer periphery of old stem; isolated group of fibres F. and rhytidome initials R.*

7 *L. S. of growing point G.P. with nine developing leaves, 1-9.*

8 *L. S. towards the apex of a young leaf; leaflets differentiating L; Undifferentiated petiolar tissue U. P., Initials of vascular bundle — mid-rib of leaflet V.B.*

9 *C. S. of a leaflet (young) upper epidermis with thick cuticle U.E; hypoderm H_1; bundle of fibres F; vascular bundle V.B; xylem X; phloem Ph. palisade parenchyma P; Spongy parenchyma S; group of water cells H_2, lower epidermis L.E.*

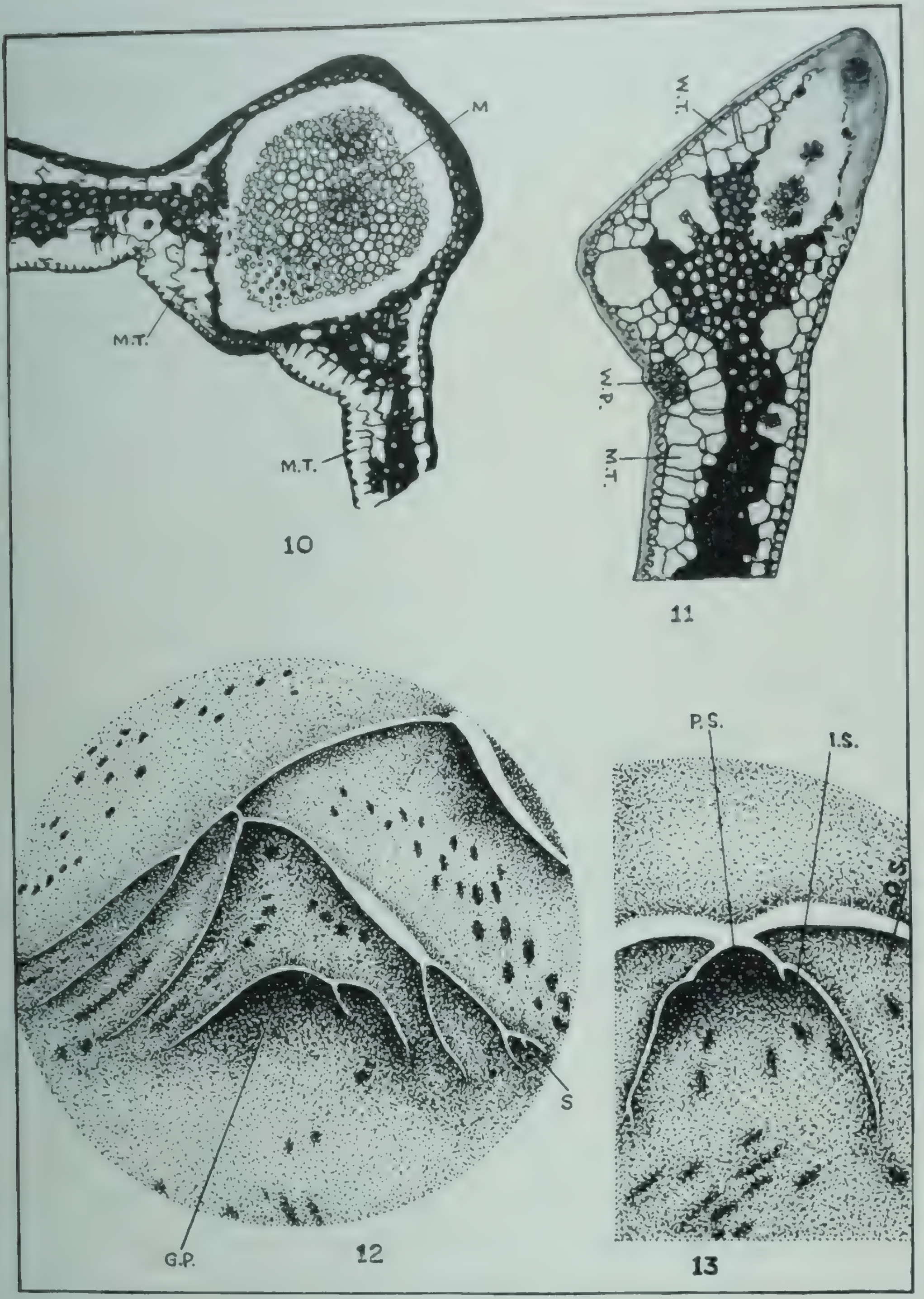

Fig. 11. Structure of the leaf
(After Patel, 1938)

10 *C. S. of Mid-rib of an old leaflet with bases of sides; motor tissue M.T; mid-rib M.*

11 *C. S. of margin of old leaflet; motor tissue M. T; water tissue W. T.*

12 *L. S. of growing point G. P; primordium of inflo. about 32 months before the opening of the spathe S.*

13 *L. S. of the 20th inflo. in the 37th leaf axil about 21 months before the opening of the spathe; outer spathe O. S; inner spathe initials I. S; primordium of spadix P. S.*

dividing cells closely invested with three to four rows of small cells form the growing point which has the three primary meristems; just below this, numerous procambial strands make their appearance. In this region, the cells are bigger than in the growing point. The strands are isolated and scattered all over the tender stem which is rich in starch granules and sugars. Each strand is an elongated tissue consisting of long narrow cells, derived by vertical division and is enclosed by a layer of cells. The cells of the strand, by repeated division, multiply to a considerable extent before the elements of xylem and phloem are differentiated. The bundles derived from the strands are closed ones and scattered throughout the stem. They are round, oval or elliptic (Fig. *8:3, 4*). The first formed bundles are bigger than those subsequently developed from the ground meristem which persists for a considerable length of time. The first formed or protoxylem vessels are smaller than the subsequently formed metaxylem. The vessels usually vary in number from three to nine and form a V-shaped tissue in the young stem, with the base towards the centre of the stem. Outside or above the xylem is a small group of phloem cells. Both the xylem and phloem are enclosed by cells which are thin-walled in the beginning and which get thickened with age thus forming the fibrous sheath of the bundle. The parenchyma close to the xylem and phloem as also a few cells in patches, of the fibrous sheath are not thickened even in the old stems. This is chiefly confined to the apex of the bundle as a broad round tissue, and the base of the bundle is practically without the fibres. The xylem tissue, V-shaped while young, changes its shape with age. It may be found in two or three groups. The big bundles (Fig. *8:3*) with many xylem vessels are comparatively few. The most common type of bundle in the old stem, is the second type with only one big xylem vessel, a small phloem tissue above and a broad fibrous tissue lying outermost in the bundle. The vascular bundles at the centre of the stem are more widely spaced than those towards the periphery. In the periphery itself the vascular bundles are few or practically nil; instead, there is a large number of small groups of fibres (Fig. ***10***: *5, 6*) derived from the ground meristem. Between the central part of the stem and the periphery, the bundles are closely packed with just a few layers of thin-walled cells intervening (Fig. *8:4*). At times, the separating parenchyma is wanting and two bundles come to lie so close that they unite into a double bundle. The increase in the size of the bundle from the young to the old stage is very considerable. The cortex consists of several layers of thin-walled parenchyma and a layer of epidermis with the outer wall much thickened. Tannin cells and ducts occur in places where the parenchyma is present, but they are mostly confined to the peripheral layers.

The periderm or cork tissue common in most plants is absent in both the root and the stem. Instead, there is a peculiar "storied type" of cork cells called the rhytidome (Fig. ***10***: *6*). It occurs at the periphery of the stem.

There is no cambium and consequently no secondary thickening in the coconut. But the stem of the tree is stout while that of the seedling is thin. It should not be assumed that the thin stem of the seedling becomes thicker to form the thick trunk of the tree. The thin stem of the seedling remains so throughout the life of the individual. The meristematic activity of the growing point increases with the age of the seedling so that more and more cells and vascular bundles are produced resulting in a thicker stem as the seedling grows older, thereby forming the bole which is like an inverted cone. After the bole is formed, a stem of fairly uniform girth begins to appear.

THE LEAF

Every tree has a crown of leaves orientated at the top of the trunk consisting of opened leaves and those in the bud in various stages of development. The number of leaves in the crown varies depending on the conditions prevailing, viz., method of cultivation, nutritional status of the soil, sunlight, etc.

In adult trees, the crown comprises about 30 to 40 opened leaves. There are generally four sets of leaves in the crown. The first set consists of ten to twelve leaves counted from the oldest leaf, from the axils of which the bunches have already been harvested. The majority of these according to Sampson (1923), are of very little value to the tree having past their prime. The next set consisting of ten to fourteen leaves will be those supporting fruit bunches in the different stages of development. The third set includes ten to twelve opened leaves in the axils of which are found spadices in various stages of development. The last set comprises of leaves in the cabbage of which the few outermost ones will be in different stages of unfurling, the rest being those which have not yet protruded.

The soft and brittle bud in the centre of the crown is the most rapidly growing part of the tree. The bud is rich in phosphates and potash and has a 'nutty' flavour It is considered a great delicacy. The number of leaves inside the 'cabbage' has been determined by Patel to be generally ranging from the same number to one and a half times the number of leaves opened outside. The bud is protected by stipules, which form a sort of fibrous bandage binding the tender leaves. This fibrous sheath persists for some time till the leaves mature and become strong enough to withstand severe winds.

The bud produces leaves in succession. The young leaf first appears in the centre of the crown as a pointed arrow and in this stage all the leaflets are held together. The top leaflets open out as the leaf grows and it takes four to five months to completely emerge out of the sheath. The leaf is considered to be fully open when the lowermost of the leaflets has emerged. When the tip of the leaf appears in the centre of the crown it is in line with the stem, i.e., almost perpendicular to the ground. It is then gradually pushed to one side to provide space for the younger set of leaves. As the leaf gets older, it bends down and by the time it dries up and is about to shed, i.e., within about two and a half to three years from the emergence of the leaf, it would have covered an angle of 120° to 170° with the stem. The tip which once faced the sky now points downwards to the ground. The leaves of young trees cover an angle of 80° to 90° by the time they are shed. Each leaf covers a greater angle as the number of leaves increases in a tree.

The leaves are so arranged on the crown that each leaf gets the maximum amount of light. This is secured by an arrangement of leaves on the crown in five spirals which run in clock-wise or anti-clockwise direction giving rise to right or left spirals respectively. The phyllotaxy of each spiral is nearly two-fifths, *i.e.,* an angle of deflection of any two successive leaves in a spiral is nearly 144°. Sampson has, however, given the angle of deflection as 142° though further studies have shown that the angle of deflection may range from 137° to 141°. Starting from the first leaf and making nearly two complete rounds of the stem the sixth leaf is reached, which is not exactly over the first leaf but is deflected by 15° to 35°. The angle of deflection between successive leaves is found to vary to some extent from tree to tree and also in the same tree according to age.

If the bunches hang towards the right of the petiole, the spiral is towards the left and when the bunches hang towards the left of the petiole, the spiral is towards the right. Even though the direction of the spiral varies in different trees, it remains the same throughout the life of any particular tree.

The leaf consists of a rachis popularly known as leaf-stalk (or petiole) and the leaflets. The leaf-stalk continues as a mid-rib or rachis till the tip of the leaf where it merges into the green leaflets. The upper half of the leaf can withstand strains from above as well as from the sides. The leaf stalk attaches the leaf to the stem by means of a sheath in the form of a bracket firmly clasping the stem with its wings nearly round it, providing mechanical strength to it to withstand considerable strain from the wind and the weight of the bunch. The centre of attachment is, however, not so strong, for if the joint at the wings is cut, it is quite easy to tear away the leaf from the stem which is still quite tender where it is protected by the thick butt of the leaf bracket. When young, the stipules form a part of the leaf stalk and surround the whole stem. In young trees these stipules frequently persist unbroken till the leaf dies.

The shape of the leaf stalk is of importance and there is a certain natural variation in this. The upper surface is nearly flat or just sufficiently grooved to prevent water from running to its side. The groove down the centre of the mid-rib is of interest as this canalises sufficient water which is allowed to run down into the crown and from there down the stem to the base of the bole. The lower surface is a round keel which thickens out considerably at the base thus forming a supporting bracket. This rounded keel should be deep, as a shallow keeled leaf stalk is unable to support the weight of the green bunch. At the same time the leaf stalk should be wide so as to lessen the chances of the bunch from slipping off the support. The leaf stalk should also be short, as a short leaf stalk denotes a short bunch. If the stalk of the bunch is short, the bunch will be nearer to the stem and this brings about less strain on the leaf bracket.

The length of the leaf ranges from 4·5 m to 6·0 m and varies with the fertility of the soil and vigour of trees (Davis, 1954). In old trees which have lost their vigour, the length will be very much reduced and may not be more than 3·5 m. Of this total length, a little less than a quarter represents the length of the leaf stalk. The number of leaflets on a leaf varies from 200 to 250. Where the number is small the leaflets are usually narrow and are farther apart, which is an undesirable character. The leaflets near the base of the leaf as well as those near the apex are much shorter and narrower than those situated in the middle. Those near the base are about 76 cm in length and about 2·5 cm in width. Those near the apex are not more than 45 cm in length and are less than 1·3 cm in width. The longest leaflets are in the lower one-third of the leaflet-bearing region. They measure about a metre in length and vary in individual trees. It is thus clear that there is great variation in the area of the leaf surface in different trees.

The attachment of leaflets at different parts of the leaf varies greatly, but in all cases it is so arranged that it throws water off the mid-rib down the leaflets so that it drips down at the ends. In the case of young leaves, these are more or less vertical and in this case any water falling on them runs down into the crown. The leaflet consists of a central strong mid-rib with a blade on each side. The blade is tough and leathery with green shining upper surface. The leaflets partially close longitudinally in the shade, cloudy weather or at night, while in full sunlight they remain open.

DEVELOPMENT AND STRUCTURE OF THE LEAF

The development of the leaf has been traced by Patel (1938). The primordium of the leaf is first differentiated about thirty months prior to its emergence from the leaf sheath. In the beginning, the leaf primordium is a small indistinct protuberance at the base and on the side of the growing point. By periclinal and anti-clinal divisions of the cells, the protuberance, in about a month's time, increases in size and assumes a finger like process with 7 to 10 layers of cells (Fig. ***10***: 7 & ***11*** :*12*). At this very early stage, the three primary meristems, *viz.*, the dermatogen, the periblem, and the plerome can be distinguished in the growing point. The outermost layer of cells forms the dermatogen which is continuous with the growing point. The three layers of cells below the dermatogen form the periblem and the plerome is innermost in the growing point. During the succeeding month the size of the protuberance considerably increases and assumes the shape of a hollow cone enclosing the next younger leaf and the growing point. At this stage, the initial cells of the procambial strands which will ultimately become the vascular bundles, first make their appearance in the central tissue or plerome of the base of the second leaf from the growing point of the stem. The procambial strands consist of elongated cells actively dividing along their length lying in the middle of the leaf where they are in 5 to 6 rows while along the margins they lie only in one central row. The number of strands later increases as the leaf develops in size.

The young leaves are without laminae and they consist of only the petiole portion at the apex of which is a growing point with the primary meristems. The leaflets are first differentiated at the tip of the seventh leaf from the growing point in about eight months after it originated. The differentiation of the leaflets occurs first below the top of the young petiole on either side of it.

The growing point of the leaf produces a thin sheet of living tissue on either side, which gradually becomes thicker and later develops perpendicular splits to the axis and these do not extend to the very margin. Narayana (1938) observed that long narrow rectangular mass of cells about 18 layers thick and united on the outer margin are formed and these develop into the leaflets. He observed subsequently, another split along the length of the tissue and in its middle, forming the sides of the leaflets which denoted that the leaflets are not formed from separate growing points but derived from one tissue. The epidermis either upper or lower, is derived only from the plerome or ground meristem, and not from the dermatogen. Patel (1938) on the other hand observed that the formation of the leaflets and their plicate nature in the bud are due to invagination by differential growth (Fig. ***10***: *8*). He also observed the un-differentiated part in the middle of the petiole developing into the main rachis and the apices of the top leaflets into a solid elongate tip. At an older stage it consists of two closely packed groups of large, much thickened vascular bundles with smaller ones by the sides. According to Narayana, the leaflets are formed and differentiated about a year before the opening of the leaf and as they develop they assume a vertical position.

The procambial strands of the mid-rib of the leaflets are the first to form and are later followed by those of the sides. The formation of the xylem of the sides occur about two months after that of the mid-rib. This is followed by the formation of the cross veins just after the xylem elements are differentiated on the sides of the leaflets. The mature leaflet (Fig. ***11*** : *10*) consists of a strong mid-rib in the middle from which slant down the two sides of the leaflet (Fig. ***10***: *9*). Epidermis is observed on either side of the leaflet with thick outer cuticle. The lower epidermis is thinner than the upper. Below the upper epidermis there are two layers of hypoderm that serve as water storage tissue while above the lower epidermis there is only one broken layer of hypoderm. Below the upper hypoderm is the broad palisade tissue spreading down to very nearly the lower hypoderm consisting of thin-walled elongate and closely packed cells. The spongy parenchyma is scanty or absent.

There are about 20 to 25 vascular bundles running lengthwise on each side of the leaflet of which five or six are big and the rest narrow. Each of these 20 to 25 bundles occupies practically the whole thickness of the leaflet from the upper hypoderm to the lower. Each bundle consists of a few tracheids, one big vessel, a band of phloem elements on the lower side and a very narrow ring of fibre encircling the vascular bundle. In between every two big vascular bundles, and just above the lower hypoderm there are three diminutive vascular bundles made up of a few tracheids with scaleriform thickenings, three or four phloem elements and a small group of fibres. At the top of the petiole there are as many as 500 to 1,000 vascular bundles. Additional mechanical strength is afforded by small groups of fibres alternating with the small vascular bundles. On the lower epidermis numerous multicellular, dark brown, shortly stalked scales containing tannin occur at regular intervals in short depressions. Bundles of crystals of raphides occur all over the lower epidermis.

The mid-rib of the leaflet is a strong structure. The upper epidermis which is continuous with that of the sides of the leaflets is highly cuticularised. Below the epidermis are two layers of hypoderm continuous with the upper hypoderm of the sides of the leaflet. Then follows the two or three layers of parenchyma encircling the ring of fibres. Enclosed within the fibrous sheath there is a ring of seven or eight vascular bundles. Of these, the innermost or the basal bundle is the biggest with a broad patch of phloem tissue and a conspicuous ‘ cap ’ of thickened fibres. The phloem may, at times, be in two or three distinct groups. The rest of the bundles are much smaller but each having a conspicuous group of phloem tubes. The cells forming the ground tissue are also thickened. The stomata are first formed about three months before the emergence of the leaf, and are mostly confined only to the lower surface of the leaflets. There are nearly 200 stomata in each square mm on the leaflets. They are fairly large being $38\mu \times 40\mu$ including the subsidiary cells and $38\mu \times 19\mu$ excluding them. The distribution of stomata is regular and they occur in two to four longitudinal rows in between every two vascular or fibre bundles along the length of the leaflet. The stoma is elliptic with two guard cells having large starch grains and a narrow opening. There is a subsidiary cell bordering each guard cell, and the two subsidiary cells are joined by a small square cell at either end of the stoma.

The attachment of each half of the leaflet to the mid-rib is narrow and tapering, in the young leaflet, before its opening. The place of attachment is strengthened by a group of fibres. There is also a special motor tissue bordering the inner epidermis which is thrown into folds and is continuous with the lower epidermis of the leaflet. In the young leaflet, the motor tissue is not functional and consists of narrow elongated thin-walled cells which are also much compressed. Behind the motor tissue are a vascular bundle and a patch of parenchyma. By the time the leaflet is about to open, the motor tissue develops considerably and consists of two rows of big cells. The cells absorb the water supplied by the small vascular bundle lying behind the tissue and become turgid, and a lateral push is exerted on the sides of the leaflet, which gets separated from the oppressed position in the bud and remains at an angle. The bundle of fibres at the base of the attachment of the sides acts as a pivot on which the side moves. The motor tissue which runs the whole length of the mid-rib persists in the old leaf and helps the sides of the leaflet to remain in position. Due to the thick cuticle of the epidermal folds sudden movements are checked.

The outer margins of the sides of the leaflet are peculiarly folded each being somewhat like a hook (Fig. ***11*** : *11*). One margin is folded on the upper epidermis and the other on the lower, so that they point towards the same direction. At the bend of the fold, the epidermis is in short folds. Behind the folds is a motor tissue, which, before the opening of the young leaflet consists of narrow, elongated, much compressed cells in one or two rows. This motor tissue is much like the one described previously and found developed at the time of unfolding of the leaflet. When the cells become quite big and turgid, they exert an outward pressure, with the result that the fold is straightened and interlocked margins are released, thereby helping the leaflets to unfold.

In the old leaflet also, the tissue persists. But in some, it is lost, and the margin is only a truncate structure thicker than the leaflet. At the upper and lower angles of the straightened margin in the old leaflet occur epithelium or water tissue of thin-walled cells and also water pores for letting out surplus water. By the turgescence of the motor tissue internal pressure is created and exerted on the water tissue.

In addition to the two motor tissues described above, there are two more at the base of the leaflet. Of these, one is situated at the angle made by the inner leaflet on the main rachis. The other is on the inner side of outer half of the leaflet where it is attached to the main rachis of the leaf. This motor tissue is continuous with that of the mid-rib of the leaflet. The tissue is made of seven tiers of much elongated living cells, closely placed side by side, within the two minute lobes of the motor tissue, visible to the naked eye. The cells towards the base and the top of the tissue are shorter than the middle ones. At the base, a small vascular bundle that supplies moisture to the tissue traverses it. The epidermis is cuticularised but not thrown into distinct folds as in the motor tissue (described previously). The function of the first tissue is to spread out the leaflet as a whole, from the erect position in the bud. The second one not only acts as a hinge when the leaflet spreads out but also helps to keep the outer half of the leaflet in position.

Thus there are four different motor tissues in the leaflet — one pair running the whole length of the mid-rib, one at the margin and two at the base.

The petiole sheath is first formed as a wing on either side of the petiole, about a year after the leaf is differentiated. The young sheath is made up of a mass of parenchyma forming the ground tissue in which are scattered a number of procambial strands. As the leaf matures, the strands become vascular bundles of considerable length and size as in the stem. The bundles resemble those of the stem and contain a broad tissue of sclerenchyma. They are not all produced at the same time. The first formed ones have more than one xylem element and those subsequently formed from the ground tissue have each one big vessel. In addition to the vascular bundles, there are isolated groups of sclerenchyma all over the sheath especially towards the periphery. A narrow cortex can be made out in the young sheath.

The old sheath consists of closely woven fibres and vascular bundles without much of thin-walled ground tissue. The importance of the considerable extent of the mechanical tissue of the sheath is evident, as encircling the stem, it has partly to bear the weight of the leaf in the developing bud. As the petiole of other young leaves enclosed in the sheath develops, it is gradually torn up.

As observed with the development of the leaf at the distal margin, a thin narrow tissue occurs uniting the tips of the young growing leaflets. The tissue may be completely used up, as the leaflets mature. But usually towards the top portion of the leaf which is first emerging, the structure persists forming a long drawn tip. It is made up of two processes one from either margin of the leaf, and consists of closely packed vascular bundles in two rows. The process has a deep constriction. The bundles are the continuations of those in the leaflets. The long drawn narrow structure at the tip of the main rachis is different from those described.

The old leaflet consists of a central, strong mid-rib from which slant down the sides of the leaflet. There is an epidermis on either side with a thick outer cuticle. Below the upper epidermis, there are two layers of hypoderm that serve as water storage tissue, but there is only one layer of hypoderm inside the lower epidermis, with groups of three big cells occurring at intervals. The hypodermal cells are thin-walled and much bigger than those of the epidermis. Just inside the hypoderm on either side of the leaflet, particularly on the lower, occur groups of fibres which afford strength and rigidity to the leaflet.

There are nearly twenty to twenty-five vascular bundles running lengthwise on each side of the leaflet. Of these, five or six bundles occupy practically the whole thickness of the leaflet from the upper hypoderm to the lower. They are narrow or elliptic, somewhat like the bundles of the stem but with much narrower fibrous sheath.

Below the upper hypoderm is the broad palisade tissue spreading down to very nearly the lower hypoderm. The palisade cells are elongate and closely packed. Below the palisade tissue is a scanty spongy parenchyma made up of a few cells. The chloroplasts are formed in the mesophyll just prior to the emergence of the leaf.

EFFECT OF ENVIRONMENTAL AND OTHER FACTORS OF LEAF CHARACTERS

Results of detailed studies on the above aspects have been reported by Patel (1938). The number of leaves present on the crowns of trees at any one time varies according to the age of the palm and the rate of production and shedding of leaves. In one-year-old seedlings generally seven to nine leaves are found. As the tree grows in age the rate of production first increases, then becomes more or less steady and declines in old age. In a group of grown up trees Patel found the number of leaves to vary from 22 to 35.

The rate of production of leaves is influenced by the age, vigour, fertility of soil, cultural and manurial practices and seasonal conditions. The beneficial effect of manuring and cultivation on the production of leaves has been referred to by Patel. In a fertile soil the rate of production is much more than in an infertile one. The rate of production of leaves is also influenced by season. Thus, on the South West Coast of India, the rate of production of leaves is low during summer and is rapid during September-October. Trees showing greater rate of leaf production in general give better yields than others.

Under favourable conditions the leaves of good bearers remain on the palms for 3 to 3½ years after they have fully opened out. The life of the leaf is less in poor bearers than in medium or heavy bearers. According to Patel, the number of leaves shed is influenced by seasonal and probably soil conditions also.

The length of the leaf is also influenced by factors such as variety, soil and climatic conditions, and age of the trees, etc. Patel has recorded that manuring has resulted in the production of longer leaves.

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CHAPTER III

FLORAL BIOLOGY

The commencement of flowering is an important stage in the life of the coconut. Petch (1913), Aldaba (1921), Furtado (1924), Kidavu and Nambiar (1925), Marechal (1928), Huggins (1928), Jack and Sands (1929), and Liyanage (1949, 1950) have studied different aspects of the floral biology of the coconut.

COMMENCEMENT OF FLOWERING

The age at which the tree flowers varies according to the type of the palm, soil and climatic conditions. Jack and Sands reported that in Malaya, the dwarf palms flowered in the third year after planting and among these, those with yellow coloured petioles flowered earliest and those with green coloured petioles last. They also reported that generally the first to germinate were the first to flower. Some palms, particularly those having large number of leaves, flowered earlier than palms having small number of leaves. Patel (1938) observed that while the earliest flowering in the tall variety of palms was about the fifth year, the majority of the palms flowered only by the end of the twelfth year and the number flowering after the twelfth year was small. He observed that by the end of the thirteenth year, about 90 per cent of the trees flowered. He adduced considerable experimental evidence to show that there was no difference in the mean age at which trees planted on the surface and those planted one foot deep commenced to flower.

NATURE OF BEARING OF SPADICES

Spadix

After a tree has commenced flowering, when each leaf has an inflorescence (spadix) in its axil as is common in most of the palms, it is called a regular bearer. But when the production of spadices in the axils of successive leaves is irregular, the tree is termed an irregular bearer. In a regular bearer, therefore, the number of leaves and the number of spadices are almost the same, i.e., 12 per annum for most of the palms. Jack and Sands (1929) have recorded the following intervals between the opening of the successive spadices for dwarf palms having differently coloured petioles. Annually about 17-19 spathes are produced in this type:

Colour of petiole	*Interval in days*
Yellow	18·5 to 21·1
Red	19·3 to 24·2
Green	18·7 to 23·1

Relationship between spadix and leaf production

The number of spadices produced largely depends on the number of leaves produced. The production of leaves, therefore, to a great extent affects spadix production as well. Observations regarding the number of fully emerged leaves and the number of opened spadices in a year have been made at Kasaragod on 96 trees. The following table from Patel (1938) shows the correlation between the number of leaves opened and the spadices.

Table 10.—Frequency distribution of trees (tall variety) in percentages according to the number of opened spadices and the number of fully emerged leaves in a year—Kasaragod

No. of fully opened leaves	Number of opened spadices						
	9	10	11	12	13	14	Total
10	–	2·08	–	–	–	–	2·08
11	–	6·25	23·95	–	–	–	30·20
12	–	2·08	8·33	28·12	–	–	38·53
13	–	1·04	5·20	4·16	13·54	–	23·94
14	–	–	–	–	1·04	3·12	4·16
15	–	–	–	–	–	1·04	1·04
16	–	–	–	–	–	–	–
Total	–	11·45	37·48	32·28	14·58	4·16	–

Since the examination of the leaves in the crown reveals that every leaf has an inflorescence in its axil, the rate of production of the spadices must be dependent on the rate of production of leaves and the absence of a spadix in the axil of a leaf must be due to the abortion of the young spadix at an early stage in its development. From the dissection of the crowns, it can be noted that there are a number of short, undeveloped inflorescences which have ceased to grow and are faded in colour.

The effect of age and environment on the production of spadices

Observations recorded by Patel have shown that the number of spadices per tree is greater at Kasaragod than at Nileshwar–I. At Kasaragod, there are no trees which have less than ten opened spadices and 50 per cent of the trees produced 12 or more spadices in a year. On the other hand, at Nileshwar–I, which is only 20 miles distant from Kasaragod, only 7 per cent of the trees produced 12 spadices, and about 40 per cent of the trees produced less than 10 spadices. Corresponding to this low production of spadices at Nileshwar–I, there is also low production of leaves. This is probably due to a combined effect of the age of the tree, the nature of planting, and the nature of the soil.

The number of leaves developed as well as the number of spadices opened in a year are influenced by cultivation and manuring. The response to manuring on the production of spadices is varied for different types of trees, the poor trees responding more than the high or the medium yielders. From the following table it is clear that the production of bunches has increased during the manurial period for the poor group by 11·8 per cent and for the medium group by 5·8 per cent while the high yielding group has not derived any benefit at all.

Table 11.—Effect of cultivation and manuring on leaf and spadix production

Group according to the yield	Improvement in percentage over pre-manuring period	
	Leaves	Spadices
High	–4·12	–5·6
Medium	2·7	5·8
Poor	14·5	11·8

Seasonal variation in the opening of spadices

There is much variation in the number of spadices which open in different seasons. The interval between the opening of two successive spadices gives an idea of the rate of production of spadices. In the following table the intervals between the opening of successive spadices and the percentage of spadices opened in the year are tabulated separately for each month for Kasaragod and Nileshwar–I, for 1933 and 1934.

Table 12.—Seasonal variation in the production of spadices

Months	Percentage of production of spadices to the yearly production				Average interval in days between the opening of successive spadices			
	Nileshwar-I		Kasaragod		Nileshwar-I		Kasaragod	
	1933	1934	1933	1934	1933	1934	1933	1934
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
January	4·5	4·8	8·1	7·8	52·9	55·9	28·0	28·8
February	9·3	10·8	8·0	7·6	53·0	55·6	26·0	28·0
March	18·5	15·2	9·5	9·5	23·2	34·5	25·0	28·5
April	12·3	13·9	10·8	10·8	18·8	24·1	23·8	25·8
May	10·5	12·8	9·0	10·0	26·1	22·5	22·2	21·5
June	6·7	6·3	7·7	8·0	30·2	25·5	26·1	23·8
July	9·0	5·2	9·0	7·6	37·3	38·1	30·1	24·4
August	10·0	6·3	7·5	7·6	46·4	50·1	32·0	27·0
September	6·5	7·6	7·4	8·0	30·7	45·9	28·0	30·2
October	4·7	6·8	9·0	7·5	28·1	37·6	26·0	29·2
November	5·4	6·8	7·0	7·6	40·2	28·9	24·9	29·0
December	3·4	1·5	7·0	8·0	47·9	34·6	26·7	27·1

The largest number of bunches opened during the month of March at Nileshwar-I and in the month of April at Kasaragod. The opening of the bunches is very low during October, November, December and January at both the places and it is generally high during March, April and May. Comparing the figures of Kasaragod with those of Nileshwar-I, it is observed that there is slight difference in the effect of seasons between the two places.

A comparison of the figures in columns 2, 3, 4 and 5 with the corresponding figures of the columns 6, 7, 8 and 9 will indicate that the interval between the opening of successive spadices is not always directly dependent upon the number of spadices opened in the month. This is easily understood if it is kept in mind that the interval is related to the preceding opened spadix, while the number of opened spadix has no direct relationship to the number of spadices opened in the previous month. This interval between the opening of successive spadices appears to remain the same for the main seasons even in different years. The mean interval between the opening of the successive spadices is low, i.e., 27·8 days for Kasaragod and high for Nileshwar-I, i.e., 33·4 days. This is mainly due to the fact that the trees at Nileshwar-I are very young.

Abortion of spadices

It has been previously mentioned that each of the leaves in the crown has a spadix (inflorescence) in its axil and the absence of a spadix in any leaf axil must be due to the abortion of the young inflorescence at the very early stage in the development. The dissection of the crowns of about 120 trees which had flowered, showed that every tender leaf had one primordial inflorescence but in the case of all the fully opened leaves only some had spadices in the axils.

The abortion of spadices is no doubt dependent on the age of the tree, it being more frequent in the young trees which have just flowered. At Nileshwar-I, only about 34 per cent of the trees had spadices in the axils of all the leaves while 60 per cent of 18-year-old trees had their spadices missing in the axil of one or more leaves. At Nileshwar-III, only one tree had produced spadices in the axils of all leaves. The majority of the trees produced less than seven spadices in a year. The following is the frequency distribution of 17-year-old trees according to the number of spadices produced in their axils:

													Trees not flowered	*Total*
No. of spadices produced	1	2	3	4	5	6	7	8	9	10	11	12	..	..
Frequency of trees	2	4	6	13	11	14	10	8	6	1	2	1	22	100

On the other hand, at Kasaragod, where the trees are older and better soil conditions prevail, only 6 per cent of the trees had one or more barren axils. In the following table the frequency distribution (in percentages) of the trees according to the number of barren axils is given:

Table 13.—Percentage distribution of trees according to the number of aborted spadices

Station	Number of barren axils										
	0	1	2	3	4	5	6	7	8	9	10
Nileshwar-I ..	33·8	13·8	18·5	13·8	4·6	6·2	6·2	..	1·5	1·5	2·0
Kasaragod	89·0	2·0	2·0	..	1·0	..	..	..	..	..	..

The season and abortion of spadices

It is of interest to record which of the spadices are aborted. Observations on 65 eighteen-year-old trees at Nileshwar-I showed that in a fairly good number of trees the spadices which were to appear in June to October were aborted. If the trees are grouped according to the percentage of abortion in the different months to the total annual abortions, they would give a clear idea of the influence of the season in causing abortion of spadices. The data are grouped accordingly in the table below:

Table 14.—Frequency distribution of trees (in per cent) according to the percentage of abortion of spadices that are to open in the different months to the total abortions

Months	Percentage of total abortions								Percentage of total abortions in each of the month
	Nil	5	15	25	35	45	65	95	
January	100·00	..	..	..	..	..	..	..	..
February	98·46	..	1·53	..	..	..	..	..	0·75
March	98·46	..	1·53	..	..	..	..	..	0·75
April	93·84	..	6·15	..	..	..	..	..	3·00
May	89·23	..	10·76	..	..	..	..	..	5·26
June	83·07	..	12·30	3·07	1·53	..	..	..	8·27
July	70·76	..	13·84	3·07	7·69	3·07	..	1·53	14·21
August	50·76	..	15·38	4·61	13·84	12·30	..	3·07	24·06
September	46·15	..	13·84	4·61	10·76	15·38	1·53	7·69	27·06
October	76·92	..	10·76	3·07	3·07	4·61	..	1·53	11·28
November	93·84	..	4·61	..	1·53	..	..	..	3·76
December	96·92	..	1·53	..	1·53	..	..	..	1·50

Number of trees observed: 65. Total number of abortions: 133.

From the table it may be concluded that there were practically no aborted spadices in the months of January, February and March. On the other hand, in about 50 per cent of the trees, the spadices that were expected to open during August and September had aborted. About 50 per cent of the total spadices aborted during the year was in these two months. About 75 per cent of the abortions was observed during the rainy months of July, August, September and October. During the dry season, the abortions were on the whole rare.

The causes for the abortions of spadices

The cause for the increased abortions of the spadices which are to open during the rainy months is worth consideration. The undeveloped inflorescences which are pale, poorly filled and shorter than the younger normal ones, have bracts, but the branches of the spadix are wanting. This would then indicate that the check in the development of the spadix is correlated to the absence of the branches. The formation of these branches first occurs about 15 to 16 months prior to the opening of the spathe. The only important factor which might obviously affect the formation of the branches is the drought at the time of their formation. In the following table, the percentages of total abortions of the spadices that are to open in the different months are tabulated along with the corresponding months during which the formation of the branches would first begin, i.e., 16 months prior. It is evident that when the formation of the branches of the spadices is to occur during the dry months, the abortions of these spadices are more frequent. This then explains why the abortions of spadices which are to open during the rainy season are more common.

Table 15.—Abortion of spadices in relation to the time of opening

Months in which the spadices are to open	Percentage of abortions in the month to the total for the year	Corresponding month, i.e., 16 months prior when the formation of the branches of spadices would take place
January	Nil	September
February	0·75	October
March	0·75	November
April	3·00	December
May	5·26	January
June	8·27	February
July	14·21	March
August	24·06	April
September	27·06	May
October	11·28	June
November	3·76	July
December	1·5	August

THE INFLORESCENCE

Inflorescences of the coconut are formed in the axils of every leaf of a bearing tree. Early workers on the coconut believed that inflorescences were formed in the axils of every third leaf. It is true that some axils fail to throw out inflorescences because the latter become abortive. But the production of such inflorescences has not been observed to have any definite relation with others.

The coconut is a monoecious plant producing male and female flowers separately on the same tree. There are also palms which produce either completely male or female flowers. The tendency to produce completely male inflorescences is frequently observed when the palm produces the spadix for the first time in its life. Sometimes, this tendency is also manifested by trees which are given rest after a prolonged period of tapping for toddy. There is also considerable variation in the frequency of bearing such inflorescences.

Some trees will produce their second or third inflorescence with female flowers in addition to male flowers, while others will not bear female flowers even in the sixth inflorescence. The coconut produces inflorescences in continuous succession. If one succeeds the other rapidly, or if the flowering period of each is sufficiently prolonged, it happens that before an inflorescence completes its flowering phase, the next one might begin flowering, bringing in chances of overlapping and consequent inter-spadix pollination. This frequently happens in dwarf palms and sometimes during the months of May, September and October in tall palms.

The inflorescence appears at first in the axil of a leaf as a pear shaped flat structure. At this time, it is completely protected by two sheaths and is collectively known as the spadix. The outer sheath is thick and fibrous while the inner one is more yellow and often fibrous and somewhat flat in nature. The outer sheath stops growing very early in the life of the inner spathe so that the latter punctures it with its hard point on its ventral side (i.e., side towards the subtending leaf) and comes out erect as a yellow, somewhat flattened cone which later on, as it grows, turns green, curves a little outwards and becomes more rounded than flat. In course of time, when the spadix is full grown, it becomes more cylindrical especially in the upper half and the distension of the inflorescence within causes great pressure on the walls of the spathe with the result that it ruptures longitudinally on the ventral side at a point about an inch and a half from the apex and extends down along a groove, and the inflorescence eventually emerges out of the spathe. Sometimes, the rupturing of the spathe takes place on its dorsal side when the spadix turns round till the inflorescence within opens out. The process of splitting is very slow. Starting from the apex, it takes about 24 or more hours to complete.

The inflorescence consists of many flower bearing ramifications or spikelets situated on a central axis or a peduncle (Fig. ***12***). Its size varies from 0·75 m to 2 m in length depending upon the individual palm. When the inflorescence is enclosed within the spathe, the branches lie close to the main axis and the whole is so tightly packed that it is quite impossible for any of the individual flowers to open before the spathe splits. Sometimes, a few flowers open as soon as the spathe splits. At other times, none of the flowers open until the branches of the inflorescence have spread out. Each branch is fringed and crowded with numerous male flowers from the tip downwards and bears lower down one or more female flowers, all the flowers being sessile or sub-sessile. Sometimes, these ramifications become spatulate and remain partially or wholly sterile. Furtado (1924) observed that sometimes the branches in an inflorescence produced secondary branches which rarely had female flowers. According to him, the occurrence of such branches was common in trees heavily manured with nitrogenous manures.

Development of the inflorescence

The development of the inflorescence of the coconut has been traced by Juliano (1926) and Patel (1938). According to them the inflorescence arises in the axil of every leaf. Patel traced it in the axil of the fourth leaf counted from the tip and observed that the primordium of the rudimentary inflorescence starts almost about the same time as the subtending leaf so that the young rudimentary leaves near the growing point have in their axils the initials of the inflorescence. According to Juliano, the whole flower cluster (Fig. **13 :** *1*) consists of a central axis, the rachis, from which the rachillae (Fig. **13 :** *2*) arise in spiral succession. At their apices the rachillae bear male flowers in the axils of tertiary bracts singly in pairs and female flowers at their bases. The inflorescence initial begins as a minute protuberance at the axil of two clasping bracts (Fig. **13 :** *3* & *4*) one of which is situated towards the cabbage and the other between the petiole and the inflorescence initial. The first primary bract (Fig. **13 :** *5*) envelops the second primary bract. Both these bracts outgrow later the whole floral cluster forming two envelopes, viz., the outer and inner spathes surrounding the actively growing inflorescence. The apex of this meristematic tissue of the inflorescence initial, shows signs of formation of the primary inner bract which later develops into a persistent inflorescence envelope. Patel observed that the primary bract is slow in growing. Juliano (1926) observed that after the spathes have formed complete envelopes to the growing point of the inflorescence, the cone gives rise to lateral protuberances which later develop into the secondary bracts (Fig. **13 :** *5*). He also observed that the lower secondary bracts tend to elongate more rapidly than those at the apex so that their tips (Fig. **13 :** *6* & *7*) are nearly as long as the apex of the main axis of the whole inflorescence.

The next stage of development of the inflorescence according to Juliano is marked by the appearance of a number of growing points on the inflorescence primordium in the axils of the basal secondary bracts (Fig. **13 :** *8*). These form the primordia of the rachillae. They elongate vertically and parallel to the main axils of the inflorescence (Fig. **13 :** *9*), leaving the secondary bracts behind. Tracing their

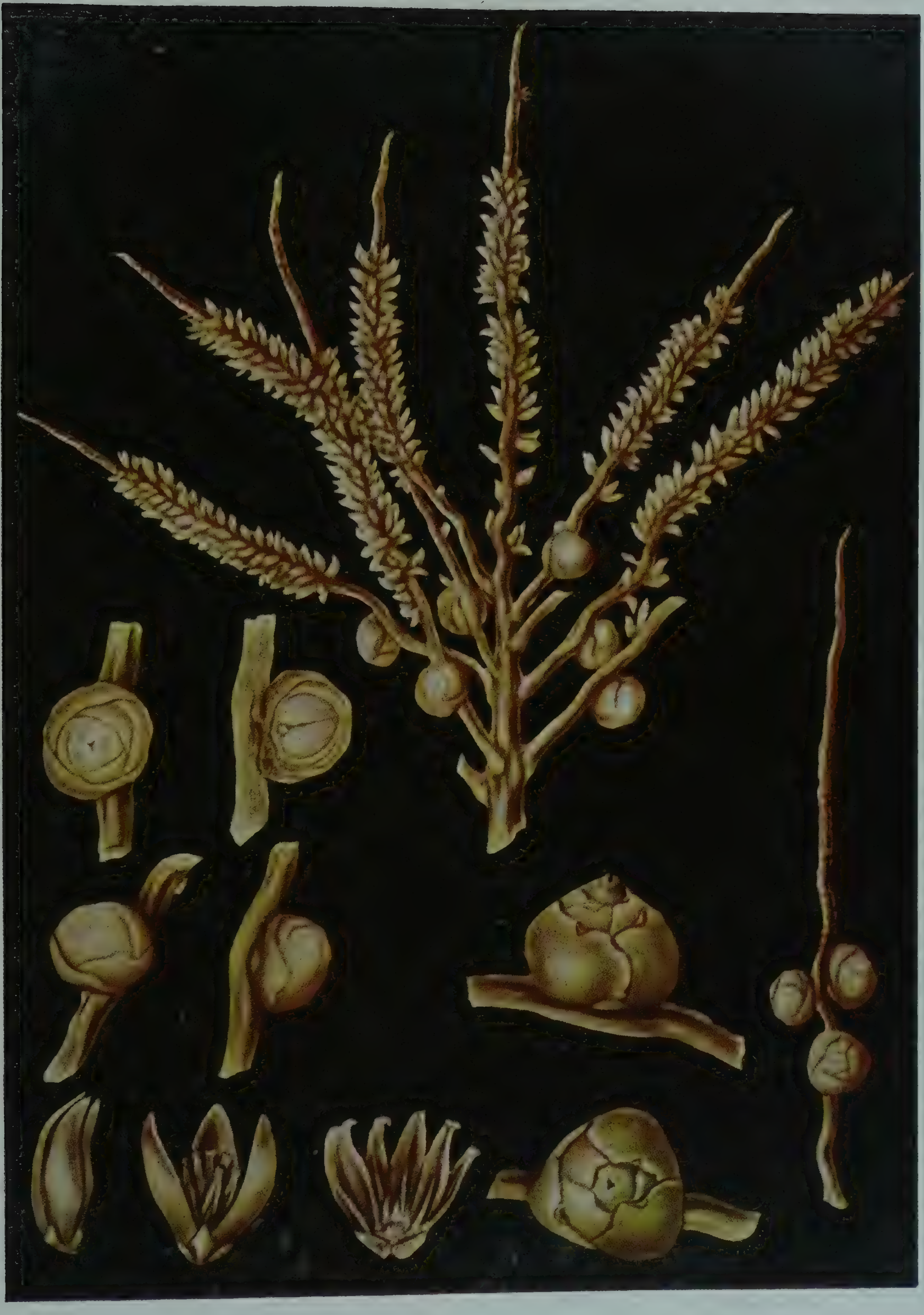

Fig. 12. Coconut inflorescence—portion of a spadix—male and female flowers (After Sampson, 1923. *Kind courtesy:* Staples Press Ltd., London)

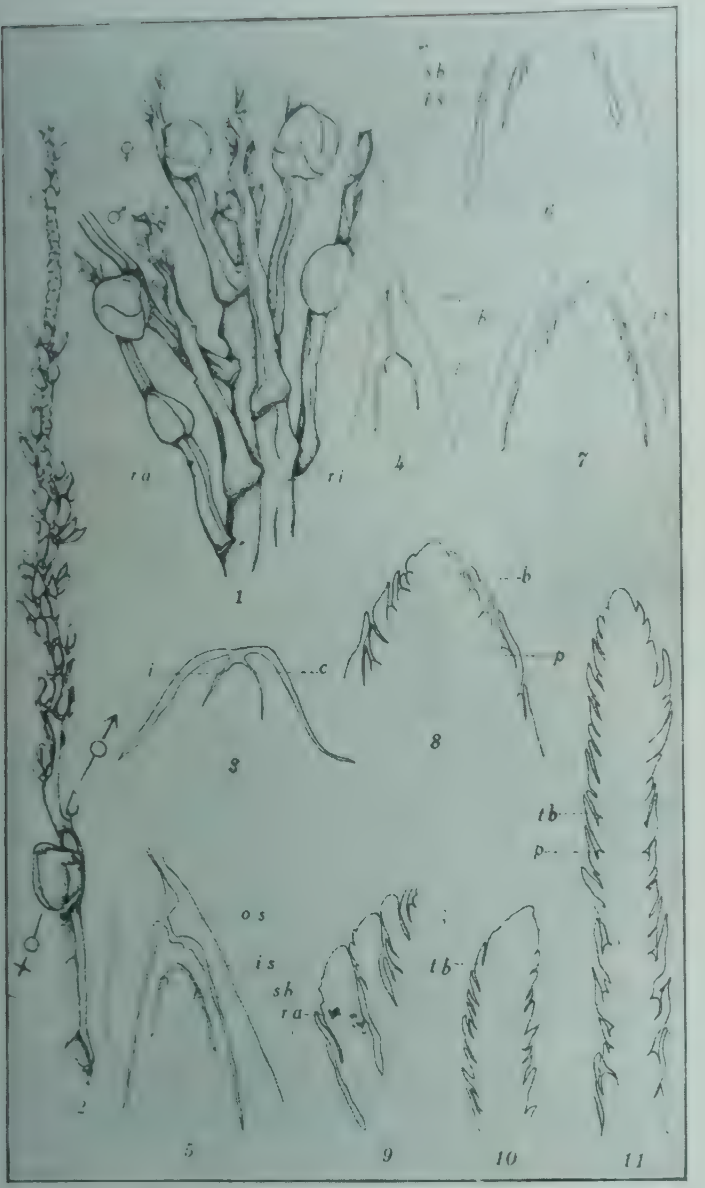

Fig. 13.
Development of the inflorescence
(After Juliano, 1926)

1 *Portion of the spadix showing rachis* (ri) *rachilla* (ra) *with male flower* (♂) *and female flower* (♀).

2 *Single rachilla showing the basal female flower* (♀) *and apical male flower* (♂).

3 *Median longitudinal section of the whole inflorescence showing primary bracts or spathes* (c) *and the beginning of the inner spathe* (i).

4 *Tangential longitudinal section of the whole inflorescence showing the outer spathe* (os) *and the inner spathe* (is).

5 *Median longitudinal section of the whole inflorescence showing the spathes* (os and is) *and the rachis giving rise to lateral secondary bracts* (sb).

6 *Median longitudinal section of the rachis showing the basal secondary bracts during rapid elongation* (sb).

7 *A much advanced stage of development of the secondary bracts.*

8 *Longitudinal section of the rachis showing the primordia* (p) *of the rachillae emerging from the axils of the secondary bracts* (b).

9 *Portion of a longitudinal section of the rachis showing the rachilla* (ra) *already developed and differentiated.*

10 *Portion of a longitudinal section of the rachilla showing tertiary bracts* (tb).

11 *A longitudinal section of a much older rachilla showing the floral primordia* (p).

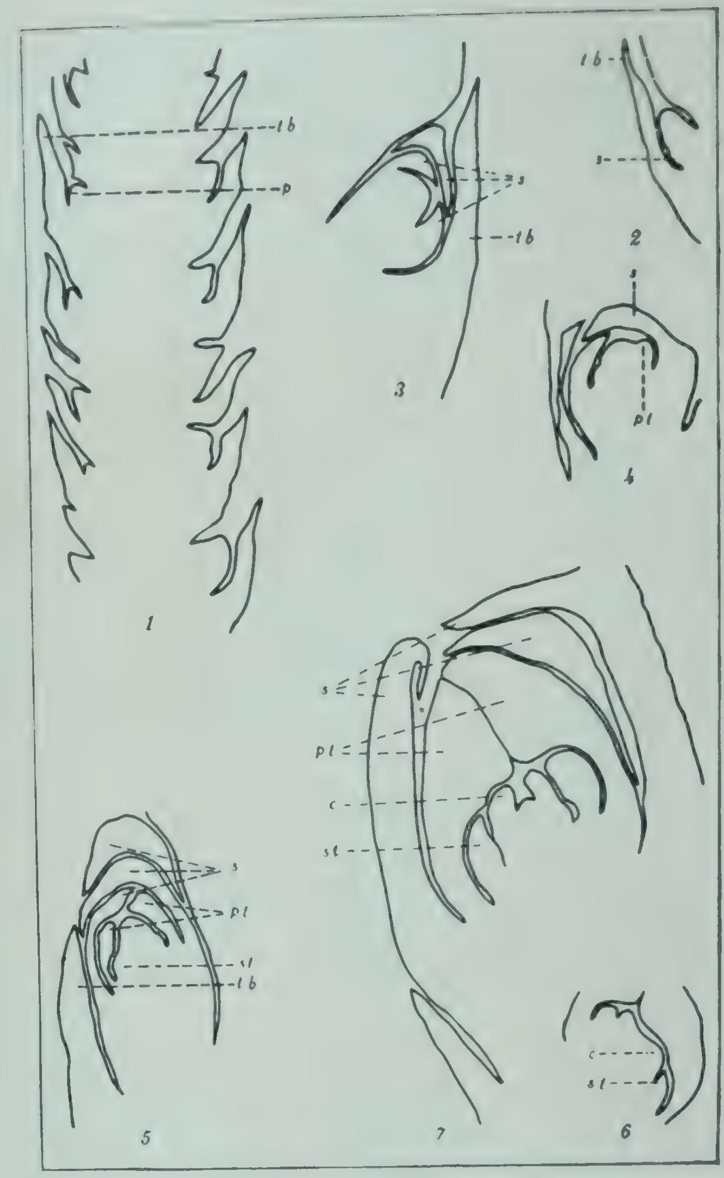

Fig. 14.
Development of the male flower
(After Juliano and Quisumbing, 1931)

1 *A longitudinal section of a portion of rachilla showing male floral primordia* (p).

2 *Longitudinal section of a male flower showing the beginning of the sepal* (s).

3 *Longitudinal section of a male flower with the three sepals* (s) *already developed.*

4 *Longitudinal section of an older male flower showing the beginnings of the petals* (pt).

5 *Longitudinal section of a much older male flower showing the sepals* (s) *and petals* (pt) *already developed, and the beginning of the stamens* (st).

6 *Portion of a longitudinal section of the male flower showing the stamens* (st) *and carpels* (c) *developing.*

7 *Longitudinal section of a male flower showing all its parts already formed.*

development further, he found that these axillary lateral primordia of the main axis of the inflorescence develop as secondary axis, or rachillae which occur in spiral succession throughout the whole length of the main axis. The main rachis almost always terminates with a single rachilla similar to its lateral branches which in their turn give rise to lateral outgrowths or tertiary bracts which serve as temporary floral envelopes (Fig. ***13**: 10* and *11*). He found the flowers developing at the axils of the tertiary bracts and all the bracts (primary, secondary and tertiary) are persistent even in the mature dried specimens. He observed that the secondary and tertiary bracts never attain great size.

THE MALE FLOWER

The male flowers exceed the female ones in the same spadix and may vary from a few hundreds to thousands depending on the number of ramifications in the spadix and the length of the flower bearing region. They are the first to open. Each male flower has six yellow perianth or floral leaves arranged in two whorls, the inner three alternating with the outer. The inner perianth parts are more than three times the size of the outer ones. Enclosed in this floral envelope, there are six hammer shaped stamens, which yield large quantities of powdery yellow pollen. In the centre of each flower, there is a rudimentary or abortive pistil which divides at its apex into three teeth, each bearing a nectar gland, the nectar of which attracts ants, bees and other insects. Rarely this rudimentary pistil is absent. A case has been noted where these abortive ovaries were stimulated to grow so that the coconut palm bore instead of a few ordinary fruits at the base of the spadix, a great number of small crowded narrow banana-like fruits. (Furtado, 1924). The flowers on the upper spikes of the inflorescence and those situated on the sides of the female flowers are the first to open and commence opening from the apex of the spike and extends downwards. Sometimes a few flowers may open out of order. The flowers bloom throughout the day, most of them blooming from 8 A.M. to 10 A.M.

The development of the male flower

The development of the male flower has been traced by Juliano and Quisumbing (1931). According to them, the male flower is borne either singly or in groups of two and three in the axil of each tertiary bract, on the rachillae (lateral branches) of the inflorescence, which is a tiny collar like structure subtending the male or the female flowers. The individual male flower, they observed, begins its development as an emergence or papillate outgrowth(*p*) in the axil of a tertiary bract (*tb*) of the rachillae (Fig. ***14**: 1*). The female and male floral primordia at this stage are not easily distinguishable from each other. Most of the floral primordia are males and only a few of the basal ones develop into female flowers. The axillary floral primordia later enlarge and assume a conical shape. According to them the first floral organs of the male flower to differentiate at the base of the floral primordium are the three sepals (*s*) which appeared simultaneously as papillate protrusions (Fig. ***14**: 2*). They found these to soon elongate, bend and cover the apex of the primordium (Fig. ***14**: 3*). As soon as the three sepals have developed, they found the petals (*pt*) to arise simultaneously, as small papillate humps within the whorl of sepals, and alternating with the latter (Fig. ***14**: 4*). They later found these elongations pushing their way between the sepals and the floral cone and covering the apex of the primordium and later fusing at their margins (Fig. ***14**: 7*). These petals were observed by them to be enclosed by the sepals at their juvenile stage but as the flower enlarges and matures, the petals outgrow the sepals (Fig. ***15**: 8*). They observed within the petals (Fig. ***14**: 5*) the six stamens (*st*) which develop as small humps after the petals have been fully formed and these differentiate early into the anthers and filaments (Fig. ***14**: 7*). The last floral organ to develop, according to them, is the rudimentary or abortive tricarpelled pistil (*c*) with style and stigma distinctly separate (Fig. ***14**: 6*).

DEVELOPMENT OF THE MICROSPORE

The development of the microspore has been examined in detail by Santos (1929) and Juliano and Quisumbing (1931). According to the latter, the microsporange at its juvenile stage is composed of a mass of homogeneous isodiametric meristematic cells delimited by an epidermis and very early it becomes faintly four lobed (Fig. ***15**: 9*) and the formation of a vascular strand (*vb*) of the connective becomes apparent. Under the lobes and simultaneous with their appearance, there is the differentiation of a plate of four to six hypodermal cells (Fig. ***15**: 9a*) which function as the archesporium (*ar*). These are distinguished from the neighbouring cells by their conspicuous size, their radial elongation, large nuclei and great affinity for stains and form a single row of cells equalling the extent of the length of the anther. These radially elongated archesporial cells all divide simultaneously (Fig. ***15**: 10*) by periclinal walls forming an outer layer, the primary parietal cells (*pp*) and the inner layer, the primary sporogenous cells (*psp*). By subsequent periclinal divisions of the primary parietal cells, definite concentric parietal tissue is formed, (Fig. **15** *: 11* & *12*) which consists of six to eight layers of cells. The outermost layer (*en*) of the parietal tissue enlarges in both directions, but more so towards the radial side and forms a distinct layer before the maturation division stage (Fig. **15** *: 13*). The inner parietal layers tangentially elongate and become laterally compressed and this feature becomes more exaggerated and reaches its maximum as the anther matures, especially at the time the microspores are formed (Fig. **15** *: 14*). Two to four innermost layers of the parietal tissues which surround the sporogenous cells (Fig. **15** *: 13*) function as the tapetum (*t*), the disorganisation of which is concomitant with the microspore mother cell stage. At the end of the tetrad formation, the tapetal cells get fully disorganised and the outer layer of the parietal tissue shows a very peculiar thickening (Fig. **15** *: 14*), a feature of the endothecium (*en*).

The development of the parietal tissue, they observed, is so rapid that the primary sporogenous cells which are at first near the epidermis of the microsporange become deeply embedded within it (Fig. **15** *: 11*). These primary sporogenous cells directly by division produce the microspore mother cells of about eight to twelve in cross section. These cells are more or less polygonal in outline and fitted tightly together. Their cytoplasm is dense and their nuclei comparatively large, somewhat spherical, with well defined nuclear membrane. About the time the tapetum shows signs of disintegration, the microspore mother cells (Fig. **16** *: 15*) and their nuclei enlarge and greatly differentiate from the adjoining parietal cells and this growth is accompanied by rounding of the cells, separation from one another and thickening of their walls (Fig. **16** *: 16*). The chromatin assumes a beaded structure and then passes into the synaptic stage. Santos (1929) observed the nucleus at this stage to be lying very close to one side of the cells, especially during the prophase and synezesic stages, but soon after the spireme begins to emerge and spread throughout the nuclear cavity, the nucleus seems to have moved towards the central part of the cell. A few cases were observed by him in which the nucleus is found close to one side of the cell during the open spireme stage and even in such cases the position of the nucleus compared with that in the earlier stages is farther from the wall.

The resting stage of the nucleus, according to him, lasts only for a short time, for, it soon goes into the prophase (Fig. **17** *: 1*) which represents a definite resting stage characterised by the somewhat uniformly distributed chromatin reticulum throughout its cavity. At the intersections between the chromatin threads and the delicate fibres connecting them, he observed minute node-like structures or granules of different sizes giving a beaded appearance. During this stage, the chromosomes completely resolve into a network of threads and their individuality is completely lost.

Heterotypic prophase

The early prophase of the first meiotic division, he found is differentiated from the resting stage by the gradual and progressive increase in size of the chromatin granules or node-like structures in the reticulum, the thickening and contraction of the threads and the decided enlargement of the nucleus. As the nuclear changes advance, he found the granules coming closer together and taking a deeper stain, while the chromatin threads contract and become thicker or shorter. The reticulum then loses the even and uniform characteristic (Fig. **17** *: 2*) and the meshes become larger and different in size. Some of the threads which have been lying far apart are apparently brought near together by their gradual contraction, (Fig. **17** *: 3*) and the chromatin threads are irregularly thickened with the nodal structures more prominent and the meshes become smaller.

Synezesis

The gradual withdrawal of the chromatin threads or network from the nuclear membrane, according to him, marks the beginning of synezesis or synapsis (Fig. **17** *: 4*). He observed during the events leading to this stage, notable and irregular progressive increase in diameter of the threads which seems to be brought about not only by contraction, but also by fusion of material from the chromatin threads that happen to run parallel to one another. Furthermore, he observed an indication of a flow of material from one thread to another, or from one part of the thread to another part (Fig. **17** : *5*). The contraction continues steadily until almost all the threads and meshes in the reticulum are drawn into a more or less compact mass that lies usually near the side of the large nucleolus and at one side of the nuclear cavity. At this stage the chromatin material appears as a lumpy mass with some globular projections, and a few small loops are found on one or two sides of the synezesic knot. The pollen mother cell nucleus remains in this condition for a long period, for the majority of the nuclei of the pollen mother cells of the younger anthers are usually observed in synezesis (Figs. ***17*** : *6, 7* & *8*; ***18*** : *9* & *10*). He also observed very frequently fine strands extending across the nuclear cavity. The nature of the spireme at this stage (Fig. ***18***: *11*) is very difficult to determine with accuracy. An examination made by him reveals that the chromatin nodes, or granules are brought very close together by contraction and arranged in single rows and in very few instances in two rows running side by side. He observed that as parallel arrangement of the granules are so rare in the material examined, the spireme is apparently univalent in nature. He observed the nucleolus greatly increasing in size and either entirely or partly covered by the chromatin knot.

Open spireme

After the period of the maximum contraction, the chromatin mass begins to loosen and it becomes a continuous univalent, short and thickened thread known as the spireme, which extends slowly throughout the nuclear cavity. He found during this gradual distribution of the spireme, that beautiful loops corresponding to the gametic number of the chromosomes are formed. At this stage he observed the spireme, more uniform in diameter, but irregular thickening due to gradual unfolding of the spireme from the sinezesis knot also taking place (Fig. ***18*** : *12, 13* & *15*). No sign of splitting is observed and the spireme is distinctly single and more or less smooth and uniform (Fig. ***18*** : *14*). While the spreading of the spireme is taking place, the nucleolus begins to separate from the spireme and its size gradually gets reduced.

Second contraction

Shortly after the spireme is uniformly spread out into wide loops radiating throughout the nuclear cavity (Fig. ***19*** : *16*), the nucleolus passes into another interesting phase of meiosis known as second contraction (Fig. ***19*** : *17, 18* & *19*).

The first indications in this connection are the gradual shortening and approximation of the sides of each loop and the progressive thickening and condensation of the chromatin threads up to which stage the chromatin thread remains distinctly single and there is no sign at all of fission.

As the process of shortening and condensation proceeds, the loops become shorter and thicker and their two sides approach each other closer, while the spireme as a whole undergoes a slow process of transverse segmentation. The segmentation according to him becomes evident from the time the loops begin to rearrange themselves in the nuclear cavity and it is apparently completed during the latter stage of second contraction indicated by the formation of the constriction usually at the distal end of the loop (Fig. ***19*** : *17* & *18*). The loops are gradually detached while the massing of the filaments is going on and he failed to find any sign of longitudinal splitting or fission which shows that each of the loops represented a univalent chromosome.

While the nucleus advances into the second contraction, the greater part of the spireme filaments gradually collect at the side of the nucleolus with the result that the visible identity of the individual parts of the spireme is somewhat lost. During the later period of the second contraction (Fig. ***19*** : *20* & *21*) there is a reduction in size of the nucleus. The pollen mother cells which, during the resting stage up to the later stage of synezesis, are packed tightly together, are beginning to round off and separate from one another, developing large spaces among them.

Diakinesis

The massing of the chromatin material during the second contraction, he observed, is of short duration as it soon loosens and proceeds into diakinesis. As the nucleus advances into this stage, the bivalent segments are gradually thrown towards the periphery of the nuclear cavity (Fig. ***19*** : *21*) and begin to show somewhat clear outline. On one side of the nuclear cavity are three distinct loops coming out from the knot and moving towards the periphery, while on the other side one or two loops are in the process of organisation. He also found that some of the chromosomes are irregularly thickened and more or less spirally twisted along their entire lengths and others show distinctly a double character and still others are slender and have a somewhat uniform diameter. In the last, the chromosomes are univalent but joined end to end. During this period of nuclear activity, the chromosomes usually tend to assume a position close to the nuclear membrane (Fig. ***20*** : *22* & *23*). This peripheral arrangement is, according to him, especially conspicuous after considerable thickening and condensation of the chromosomes have occurred.

While the paired chromosomes grow thicker and shorter, the daughter chromosomes or the members of the pair, begin to separate or untwist (Figs. ***20*** : *23, 24, 25, 26a* & *26b* ; ***21*** : *27*) and present various shapes (J's, O's, X's, Y's, U's, and V's). He also observed a few obscurely granular, fine and delicate strands which are straight, curved or crooked, connecting separate chromosomes, some running from the chromosomes to either the nuclear membrane or nucleolus and others connecting each other forming a sort of net (Fig. **20** : *26b*). He found the chromosomes appearing more homogeneous in structure and taking more uniformly a deeper stain. Their outline is somewhat undulated with no splitting, showing great diversity in their length (Fig. **21** : *28*). Sometimes, he found the chromosomes presenting a ragged appearance after the greater contraction and thickening (Fig. **21** : *29*). No material increase in the number of strands connecting one chromosome to the other or the chromosomes to the nuclear membrane is observed. In later stages of diakinesis (Fig. **21** : *30* & *31*), the paired chromosomes appear definitely individualised with a more distinct outline. Some of them simulate dumb-bell shaped bodies, and others straight or bent rods. The bivalent number of chromosomes was observed by him to be 16 and in very few instances 15, positively due to overlapping of the chromosomes.

During the late diakinesis stage and previous to the dissolution of the nuclear membrane, a notable decrease in size of the nucleolus and also the nuclear cavity is observed which modified their shape from spherical to elongated or ovoid form. A great reduction in nuclear content as shown by the presence of intra nuclear vacuoles develops in them.

The nuclear membrane, becomes more or less granular and irregular or wavy in outline and its definite and smooth appearance is gradually lost, while the cytoplasm around it becomes denser. The nuclear membrane and nucleolus disappear simultaneously at the time the fibres with granular appearance emerge from at least the three sides of the nucleus. In the late diakinesis stages (Fig. **21** : *32* & *33*), the multipolar spindle fibres are granular in structure and quite distinctly attached to the definite parts of the chromosomes and as the formation of the spindle fibres progresses, the nuclear cavity becomes smaller until it is completely filled by the fibres and by dense cytoplasmic material. The chromosomes later aggregate into a somewhat close irregular mass at the centre of the pollen mother cell.

Heterotypic mitosis

As the multipolar spindle fibres grow in number, he found them gradually rearranging into bipolars (Fig. **21** : *34*) and the spindle fibres are seen stretching and having lost their granular character, while the chromosomes, which by this time had undergone a complete process of condensation, moving towards the equatorial plane and appearing as bent rods, pestle-like or somewhat globular. The chromosomes seem to him not to have reached the equatorial region at the same time, but as soon as they reach this region, they become arranged more or less evenly in one plane and in a very symmetrical manner.

A polar view of the heterotypic chromosome (Fig. **22** : *35*) observed by him showed 16 bivalent chromosomes displaying the same variation in shape and one of them is strikingly larger than the others. The longitudinal fission between the two daughter chromosomes is very distinct, while three other chromosomes were smaller in size and appear somewhat pestle-like and do not show longitudinal fission. These formed the more favourable stages for counting the 16 chromosomes, for they are not crowded and seldom overlap each other.

The heterotypic chromosomes at the equatorial plate are arranged either radially or obliquely and each chromosome has a small bundle of spindle fibres attached to the inner end of each daughter segment, and the outer end extended perpendicularly from the spindle to the cytoplasm. In some cases, the chromosomes near the periphery or near the central part may be found arranged tangentially to the spindle, in which case, the point of attachment of the spindle fibres to the daughter chromosomes may be at either end or at or near the middle region.

The general appearance of the side view of the metaphase stage of the heterotypic mitosis (Fig. **22** : *36*) is as if the contraction of the spindle fibres gradually pulled the two longitudinal halves apart. A thickening at the middle part between the two separating daughter segments of each bivalent chromosomes consist of the two ends that have not yet separated showing that all the chromosomes divide at the same time.

Soon after the daughter chromosomes have separated, they immediately diverge at their equatorial ends, assuming several shapes with apex towards the pole. As they move toward the poles, they pass

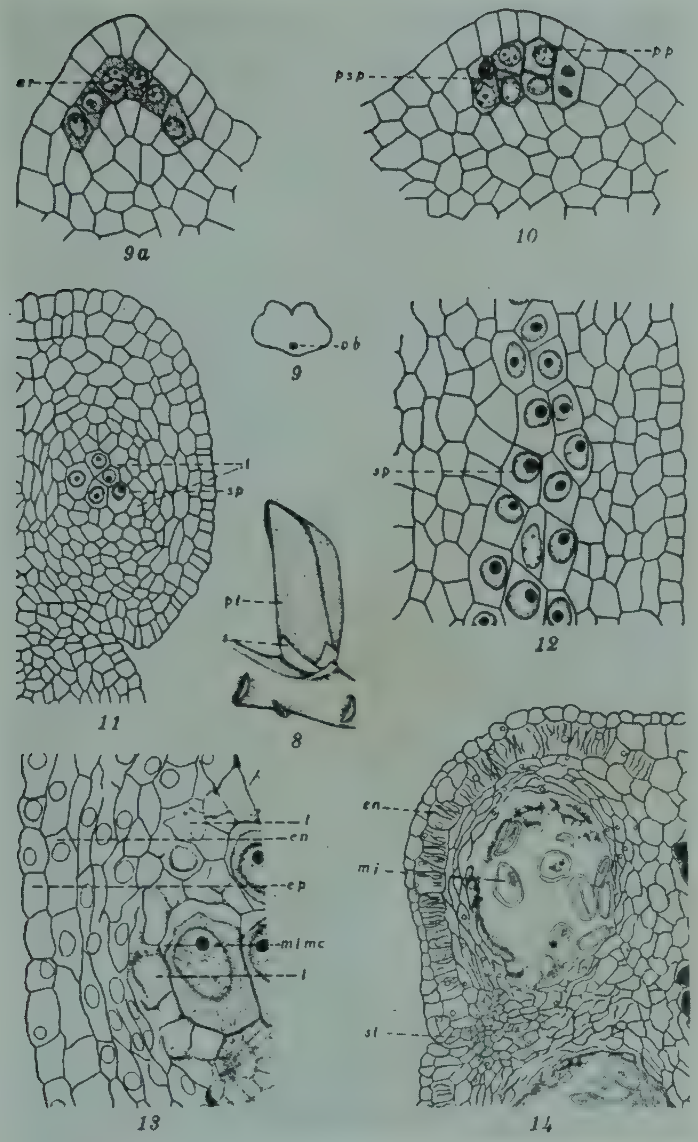

Fig. 15.

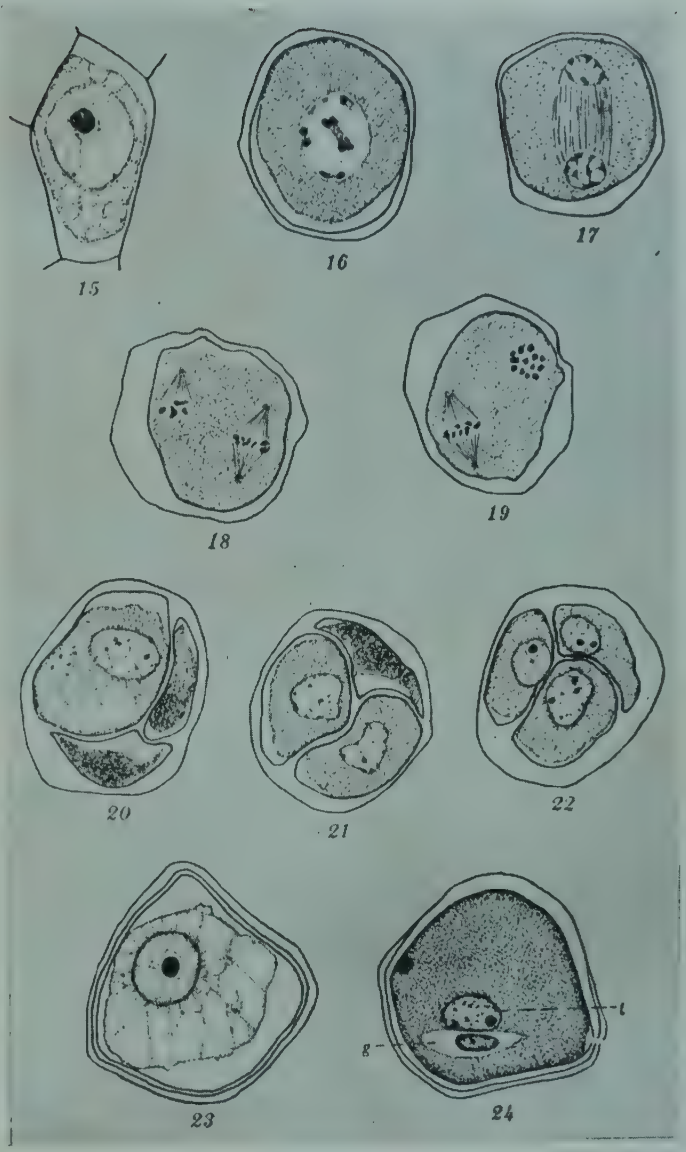

Fig. 16.

Morphology of the male flower
(After Juliano and Quisumbing, 1931)

8 *Lateral view of an unopened mature male flower showing its perianth segments.*

9 *Diagram of a transverse section of a young anther showing lobation and vascular bundle* (vb) *to the connective;*

9a *Diagram showing the plate of archesporial cells* (ar).

10 *Division of archesporial cells to form the primary parietal cells* (pp) *and the primary sporogenous cells* (psp).

11 *Portion of the anther showing the thick parietal tissue, the sporogenous cells* (sp) *and the tapetum* (t).

12 *Longitudinal section of a young anther showing sporogenous cells* (sp) *and the parietal tissue to the right.*

13 *Portion of a transverse section of an anther showing the parietal tissue, microspore mother cells* (mimc) *and the disintegrating tapetum* (t).

14 *Transverse section of a mature anther before dihiscence, showing the microspores* (mi), *endothecium* (en), *stromium* (st) *and portion of the remains of the intermediate cells of the parietal tissue.*

15 *Microspore cell in resting condition.*

16 *Microspore mother cell in diakinetic stage.*

17 *Microspore cell in heterotypic telophase.*

18. *Homoeotypic metaphase.*

19 *Homoeotypic metaphase.*

20 *Tetrad showing one of the microspores possessing distinct nucleus.*

21 *Tetard, only one of the microspores devoid of a nucleus.*

22 *Tetrad all the microspores functional.*

23 *Microspore before dehiscence showing distinct entine and exine.*

24 *Longitudinal section of the microspore at shedding stage; note the tube nucleus* (t) *and the lenticular generative cell* (g).

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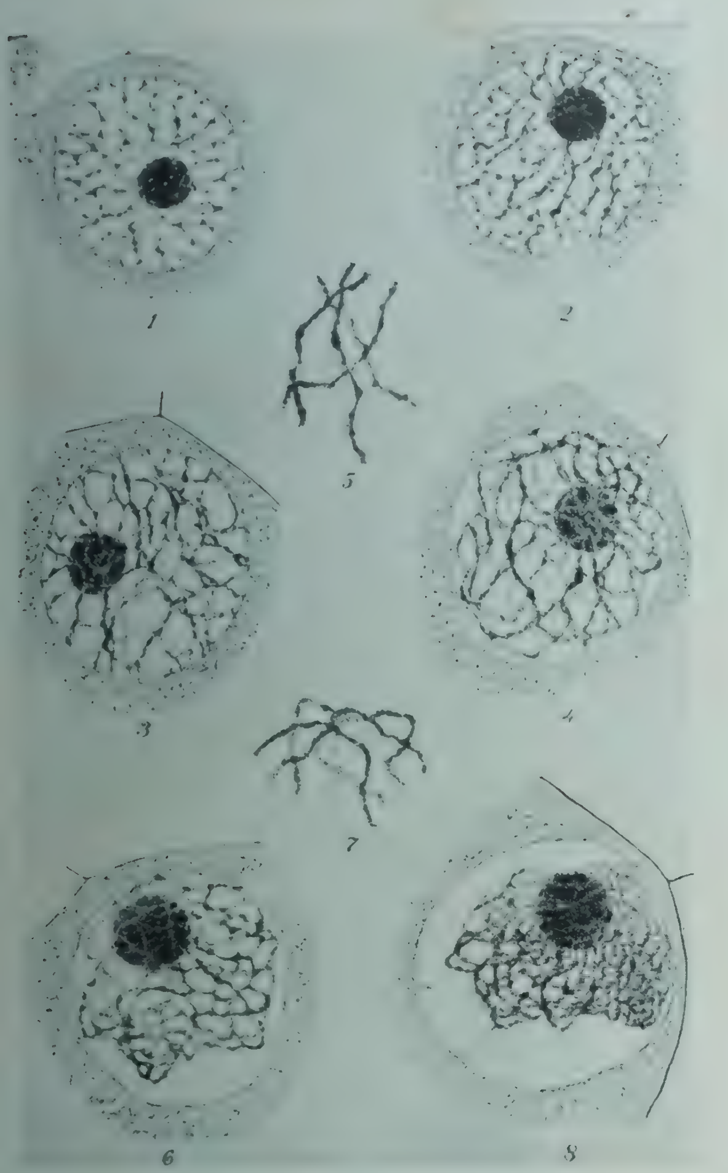


Fig. 17.

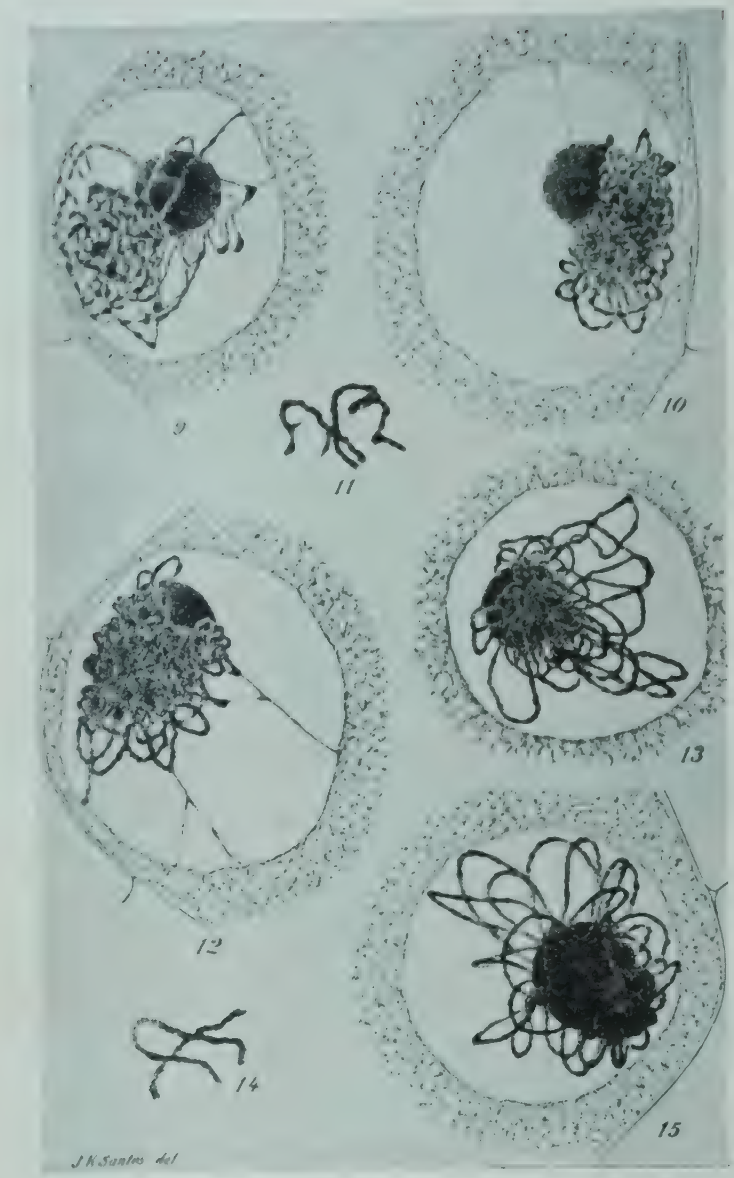


Fig. 18.

Cytological story of *Cocos nucifera*
(After Santos, 1929)

1 *A resting nucleus in pollen mother cell showing a single large nucleolus and the uniformly distributed delicate threads with nodelike-chromatic thickening.*

2 *A pollen mother cell nucleus entering into early prophase; note the irregular thickening of the threads in the reticulum.*

3 *A definite stage of the heterotypic prophase. The reticulum is more defined, consisting of fine threads with irregular thickening and nodelike chromatic granules at the junction of the meshes.*

4 *The beginning of the synezesic contraction and early stage of the spireme. Note its irregular thickening.*

5 *A portion of a superficial section of a nucleus entering into synezesic contraction in the same stage as 4.*

6 *A more definite stage of early synezesis showing the gradual withdrawal of the early spireme from the nuclear membrane.*

7 *A superficial section of the nucleus in the same stage as 6 showing the unsplit and univalent character of the spireme.*

8 *An early stage of synezesis. The unilateral massing of the chromatin threads is more conspicuous and the meshes are greatly reduced in size.*

9 *A more advanced synezesic contraction; the threads and the meshes are drawn into a close mass. A portion of the spireme is extending across the nuclear membrane.*

10 *The appearance of the spireme at the complete synezesic contraction.*

11 *A thin tangential view of the synezesic knot in the same stage as 10, showing the hazy outline and the spiral twisting of the spireme.*

12 *The univalent spireme emerging from the synezesic knot; note the delicate fibres connecting the loops to the nuclear membrane.*

13 *The loosening of the spireme from the synezesic knot and the formation of loops is well underway. The spireme appears more distinct and uniform in character.*

14 *A segment of a superficial section in the same stage as 13.*

15 *An early stage of the hollow spireme; note the loops extending towards the periphery of the nuclear cavity and the well defined and more uniform outline of the spireme.*

through a slight process of condensation and differentiation until they reach the poles, and in some cases signs of splitting preparatory for homoeotypic mitosis are observed. The anaphase in its various stages is shown in Fig. **22** : *37*. At the end of this stage, the chromosomes still retain their 'V' or 'J' shapes, although, in some cases their two ends are somewhat separated, and appear as bent rods. In a later stage, he found the sixteen polar univalent chromosomes (Fig. **22** : *38* and *39*). Later, the fission of the chromosomes in preparation for the succeeding homoeotypic mitosis becomes evident as they are congregated at the poles of the spindles. As the daughter chromosomes gather and mass together at the poles, they become surrounded by dense cytoplasm. Then a clear space or vacuole-like region develops between the chromosomes, the boundary of which becomes the membrane of the daughter nucleus (Fig. **22** : *40*) which represented a telophase stage of the heterotypic mitosis. While this clear space and the nuclear membrane are in the process of organisation, he found the chromosomes expanding and becoming longer and thinner and radiating outwards across the flattened region of the reconstructing daughter nucleus and their free ends beginning to curve, bringing into contact one end of the arm of a chromosome with an arm of another chromosome and these ends apparently fusing together. This fusion forms a spireme of short duration. In the more advanced stages (Fig. **22** : *41*), the nuclear membrane is definitely formed and the daughter 'J' or 'V' shaped chromosomes are seen connected with one another by delicate strands. In still more advanced stages (Figs. **23** : *42* and *43*) of the reconstructing nuclei, the daughter chromosomes with somewhat ragged appearance and partially condensed, are more or less evenly distributed in the nuclear cavity. The nucleus later continues to grow in size and becomes rounded.

Homoeotypic mitosis

Santos (1929) observed the succession of events during the division of the daughter nuclei is extremely rapid while the period covered from the time the nuclear membrane is formed in the late telophase up to the re-organisation of the daughter chromosomes preparatory for the second division is of short duration and the daughter nuclei appear not to pass into anything resembling a typical resting stage. He found that shortly after the nucleus has sufficiently increased in size and assumed the spherical form and the chromosomes have attained a more distinct outline, the nuclear membrane brakes down and the multipolar spindle fibres appear at different sides of the nuclear cavity. The cytoplasmic materials diffuse into the nuclear cavity while the chromosomes collect close together. He also observed the spindle fibres radiating into this mass and each chromosome attached at or close to its end by a small bundle of fibres. The multipolar spindle fibres then become bipolars while the chromosomes become arranged in the equatorial plate (Fig. **23** : *44*) with sixteen monovalent chromosomes in each set displaying various shapes and some of them globular while others resemble short, bent rods, while most of the rest are either pestle-like or dumb-bell shaped.

He observed that the two spindles may lie parallel (Fig. **23** : *45*) or at right angles (Fig. **23** : *46*) to each other or in 'V' shaped position. The majority of the chromosomes appear to be attached at the end or very close to it and exhibit the same variations in shape as did the daughter chromosomes which are observed in the equatorial plane, appearing during their separation in the heterotypic mitosis. As the grand-daughter chromosomes move away from one another and proceeds towards the spindle poles, he found them becoming 'V' shaped as in the previous division, while as they approach the poles they become considerably straightened out. During this stage, he did not observe any fission. He found the chromosomes drawing together in a mass at the poles and becoming surrounded by a denser cytoplasm, which is followed by a gradual expansion and the appearance of a clear space between them. He found ultimately, the nuclear limiting membrane making its appearance, while the chromosomes advance into a process of alveolisation. Fig. **23** : *47* presents a typical telophase stage just before the formation of the nuclear membrane and nucleolus. One of the grand-daughter nuclei after the appearance of the nuclear membrane and nucleolus is seen in Fig. **23** : *48*.

Juliano and Quisumbing (1931) in studying the later stages of development, observed that not all the microspores derived from the divisions of the microspore mother cells become functional. In nearly mature anthers they found one of the microspores in the tetrad exhibiting a very distinct nucleus (Fig. **16** : *20*) and in others only two (Fig. **16** : *21*) while in the remainder there are three (Fig. **16** : *22*). Dehisced microspores examined in water showed that some of them are devoid of granular content and therefore are sterile and these never become spherical in water and their longitudinal sutures persist. They are also found to be usually much smaller than the fertile microspores.

The division of the microspore mother cell is simultaneous (Fig. ***16*** : *17*, *18*, *19*). After a short period of adherence in tetrads, the microspores round off and acquire their coats (Fig. ***16*** : *23*). They are spherical and smooth and when dry they are ellipsoid and possess a single meridional groove or suture.

While the microspores are yet within the microsporange, they observe the nuclear division taking place giving rise to the tube nucleus (*t*) and the generative cell (*g*) (Fig. ***16*** : *24*). The microspores are observed to shed in this condition. The generative cell is lenticular in shape and its elongated and oblong nucleus stains heavily possessing denser and less regular chromatin. The tube nucleus is very much larger than the generative cell and is found to possess scanty chromatin network and large nucleolus.

The male phase

The male phase which is the interval between the opening of the first male flower and shedding of the last male flower has been observed to vary according to the nature of tree, locality in which it is cultivated and the season of the year. Patel (1938) observed that most of the flowers opened by the fifteenth day after opening of the spathes. He estimated that in about 45 per cent of the trees, the period of male phase was 18 days and in only 2 per cent or less, the duration of the male phase was 10 and 22 days. The male phase according to him was 18 days in respect of trees at Nileshwar and 18 to 25 days in respect of those at Kasaragod. He also noted that the male phase was shortest during summer months of February, March and April and a little longer during the other seasons of the year. He pointed out that, although, the duration of the male phase in July and November was fairly long, there was no justification for concluding that the duration was the longest during the rainy season. On the other hand, he observed that the differences, except for the months of April and July, were rather too small ; in the former months, the duration of the male phase was about 16 days as against 21 days for June and July. He, however, believed that this had undoubtedly some bearing on the possibilities of pollination, cross or self. In Ceylon, Liyanage (1951) estimated the male phase to last 18 to 22 days.

The Pollen

When the anthers are fully mature, the pollen sacs burst along two longitudinal slits which coincide with the partitions of the pollen sacs and shed their pollen before the opening of the male flower. Aldaba (1921) estimated that each male flower carried about 272 million pollen grains. The pollen grains are spherical and smooth when very fresh. On exposure for a few seconds, they turn ellipsoidal with a longitudinal groove in the middle and they measure about 0·063 mm in length and 0·020 mm in breadth at the centre. In the mature pollen grain, there are three nuclei one of which is larger than the remaining two. Examination of the grains under the microscope reveals the presence of shrunken grains among the smooth and round pollen grains. The former are infertile. From the counts made of the pollen of six trees, it was found that on an average about 25 per cent of the pollen grains are infertile. The variation in the percentage of infertile grains was only between 23 to 28, but Aldaba observed 3 to 33 per cent of infertile pollen grains in the Philippines.

Germination of pollen

Patel observed that the best germination of pollen grains was obtained in a 5 per cent sugar and 2 per cent gelatin water solution. Aldaba stated that 25 to 30 per cent cane sugar solution was the best for effecting the germination of the pollen grains. Liyanage (1954) observed that 10 per cent cane sugar plus 2 per cent gelatin solution was a satisfactory medium for germination. There was practically no germination in 15 and 25 per cent sugar solutions to both of which 2 per cent gelatin was added. When the pollen is placed in water, it becomes round with a diamter of 0·040 mm.

Fairly good germination was obtained when the water from tender nuts was used for germinating the pollen. The pollen also germinated in a weak solution of hydrogen peroxide (1 8000), but the growth and development of the pollen tube was very slow. That there was practically no difference in the viability of the pollen from the flowers opened at different periods on the same inflorescence was established by Patel. He also showed that pollen stored in packets of tissue paper kept in glass tubes after wrapping the packets with blotting paper germinated very well up to the third day after the storage, but the pollen lost its viability completely on the ninth day after storage. Kidavu and Nambiar (1925) reported that pollen grains were viable only up to the sixth day.

THE FEMALE FLOWER

Unlike the male flowers, the female flowers are comparatively few in number in an inflorescence. They may vary from 0 to 300 in each spadix depending on conditions prevailing, viz., nature of the tree, cultivation, manuring, season of the year, age of bearing, etc.

Jack and Sands (1929) observed that the first inflorescence produced only very few, if any, female flowers. Patel (1938) observed that there was difference in the production of female flowers among the trees as well as among inflorescences of the same tree. Jack and Sands stated that in the dwarf palms the number of female flowers per spadix was 21·4 for those having green coloured petioles and 13·6 for yellow and 10·6 for red. Patel noted much variation in the number of female flowers produced during the different months, partly due to the differences in the number of spadices opened in these months. According to him, they were generally high during March to May, the highest being in May and the lowest during September to January. Marechal (1928) on the other hand, reported that the dwarf palms in Fiji produced more female flowers during November to March. Dwarf palms generally bear female flowers in larger numbers than the tall palms.

At the time of opening of the spathe, the female flower is a small spherical body, about 1·3 cm in diameter with great resemblance to a small nut and is popularly known as a *button*. The female flowers, like males, consist of six floral leaves which are thicker, imbricately arranged and tightly folded over the inner parts of the flower completely enveloping the pistil. These are much larger and stiffer than those in the male flowers, and the outer three are almost equal in size to the inner ones. Apart from these six perianth leaves, there are two more, just at the point of attachment of the flowers to the stalk resembling the others in colour and texture but differing from them in that they are wider and shorter. These two are termed the prophylls or bracteoles. Usually, there is a male flower on each side of the female, resting on the same cushion on which the female is seated. Inside the floral leaves is a small, oval, whitish body consisting principally of embryonic tissue of husk known as pistil. In between the fleshy ovary and the perianths is a ring of suppressed stamens fringed with six teeth. From the tip of the pistil, there extend downwards three ridges which make the whole ovary look globosely three-sided, each side being provided at its tip with a groove. These three grooves meet in the centre of the apex and form the stigma. After the inflorescence opens, and before fertilisation takes place, the mass of fibrous tissue continues to increase in size and ultimately forces apart the floral leaves disclosing only its rounded upper surface which is surmounted by a white nipple. This nipple is marked by three equidistant grooves which meet at its apex and thus divide it into three triangular sections. When the female flower is ripe, these three segments separate and stand erect as three teeth, exposing the stigmatic surface on which the pollen is to fall in order that the flower may be fertilised. These three teeth constitute the stigma. Normally it is impossible for fertilisation to occur before the stigma is ripe and this does not happen until long after the opening of the inflorescence. When the fertilisation is complete, the stigma ultimately turns brown and the tissues around it collapse, forming a small black, more or less circular area containing three shrivelled teeth at the apex of the young fruit. The six floral leaves increase slightly in size, and form the whorl of perianth leaves which persist at the base of the fruit till it matures and dries.

The number of female flowers

The number of female flowers in the inflorescence is variable. There is a difference in the production of female flowers among the trees as well as among the inflorescences of the same tree. The variation among the trees of the same age and receiving the same treatment is genetical.

One hundred and fifty seven trees of Block E of Nileshwar-I, which received the same treatment and which were planted in the same year have been placed in three groups, according to their yield. The trees, the average yield of which is below ten nuts per annum were classed as poor, and those having 10 to 20 were classed as medium and those yielding above 20 nuts were classed as good trees. The yields are low because the trees are young and the soil is unsuitable. The following frequency table gives the percentage of trees in each group according to their average production of female flowers. In the type which is good, a greater percentage of the trees produces between 100 to 300 female flowers per annum per palm. The average number of female flowers per tree in the group " good " is about 151, for the group " medium " about 120 and for the group " poor " only 41.

Table 16.—Frequency distribution of trees according to their average production of female flowers

Class centres for average annual production of female flowers	Percentage of trees		
	Good	Medium	Poor
(1)	(2)	(3)	(4)
20	–	3·0	10·2
40	3·9	12·1	33·6
60	7·6	9·9	27·4
80	15·3	15·1	13·2
100	19·2	9·9	4·0
120	15·3	15·1	7·1
140	7·6	12·1	4·1
160	3·9	9·9	–
180	–	3·0	–
200	–	–	–
220	7·6	–	–
240	3·9	–	–
260	–	9·9	–
280	3·9	–	–
300	3·9	–	–
360	–	3·0	–
380	3·9	–	–
400	3·9	–	–
Mean No. of female flowers	151·5	121·8	41·0

More or less similar results are furnished by the Central Coconut Research Station, Kasaragod. The high production of female flowers in each group for the Kasaragod Station is due to the fact that the trees are older and are growing under better soil conditions :

Table 17.—Yield in relation to female flower production

Type	Kasaragod		Nileshwar-I	
	Average No. of female flowers per year	Average number of nuts per year	Average No. of female flowers per year	Average number of nuts per year
Good	396	120	152	33
Medium	264	67	122	20
Poor	156	29	41	6

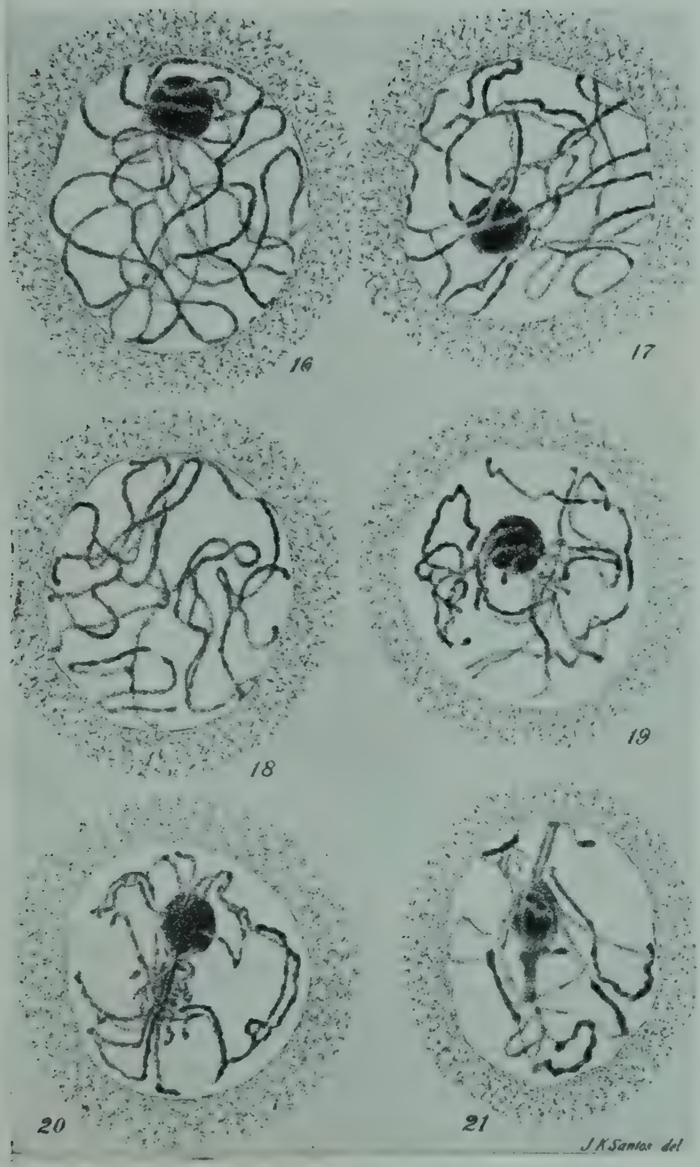


Fig. 19.

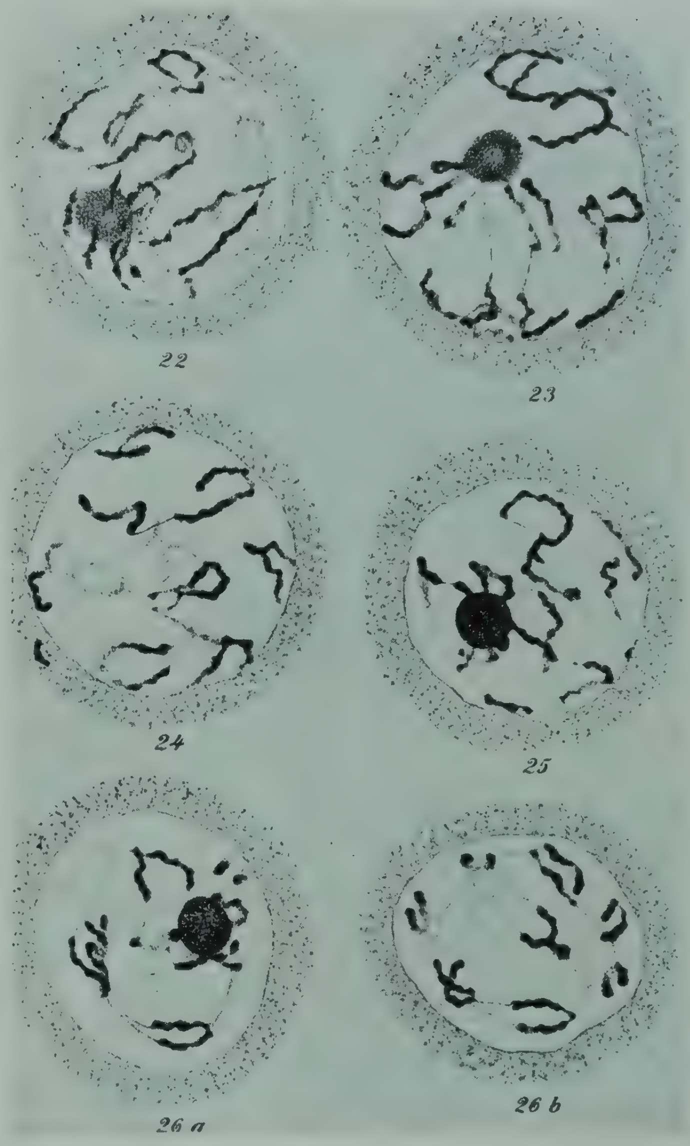


Fig. 20.

Cytological story of *Cocos nucifera*
(After Santos, 1929)

16 *A complete hollow spireme.*

17 *A later stage of the hollow spireme; the loops are shortening and sides of each loop are brought close together while the segmentation begins to take place.*

18 *Slightly older stage than the one shown in 17. The approximation of the sides of each loop and the segmentation are more evident.*

19 *Early stage of the second contraction.*

20 *A complete second contraction.*

21 *The trivalent segments coming out from the second contraction, which are greatly thickened and shortened.*

22 *The bivalent segments after the second contraction.*

23 *Early diakinesis stage. The bivalent segments are under the process of condensation and assume different configurations.*

24, 25 *Slightly older two similar stages showing the U, Y, J, O and V shaped chromosomes.*

26a, 26b *The two halves of the pollen mother cell nucleus with sixteen bivalent chromosomes.*

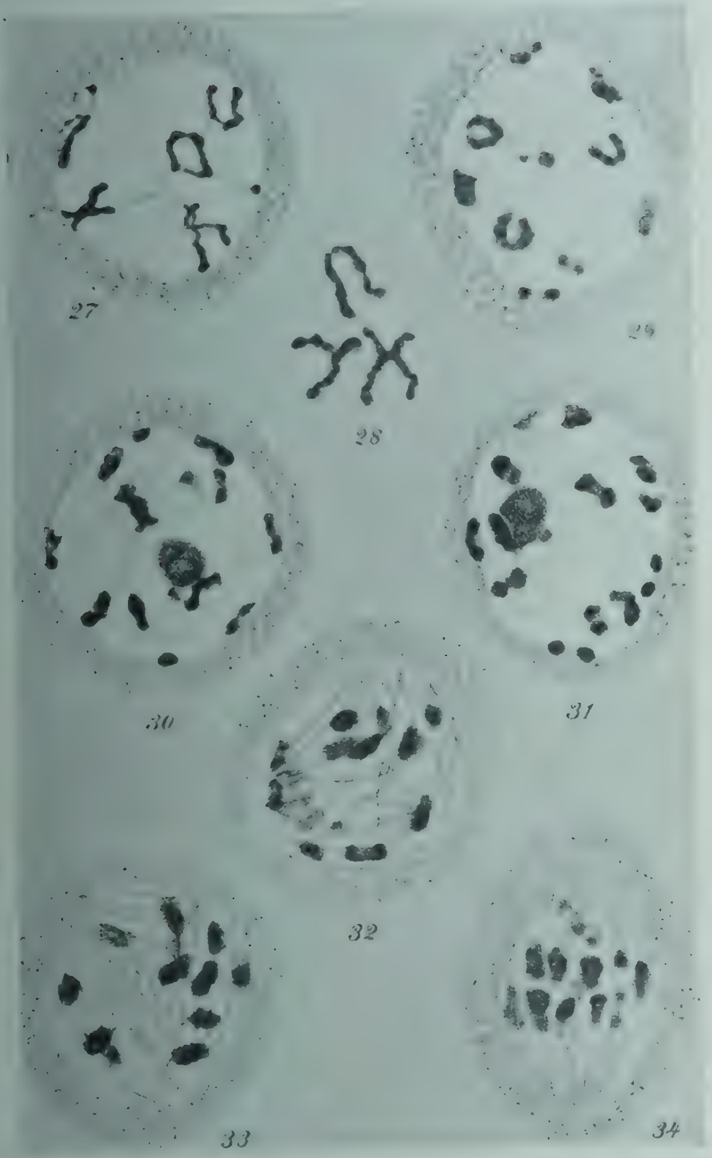


Fig. 21.

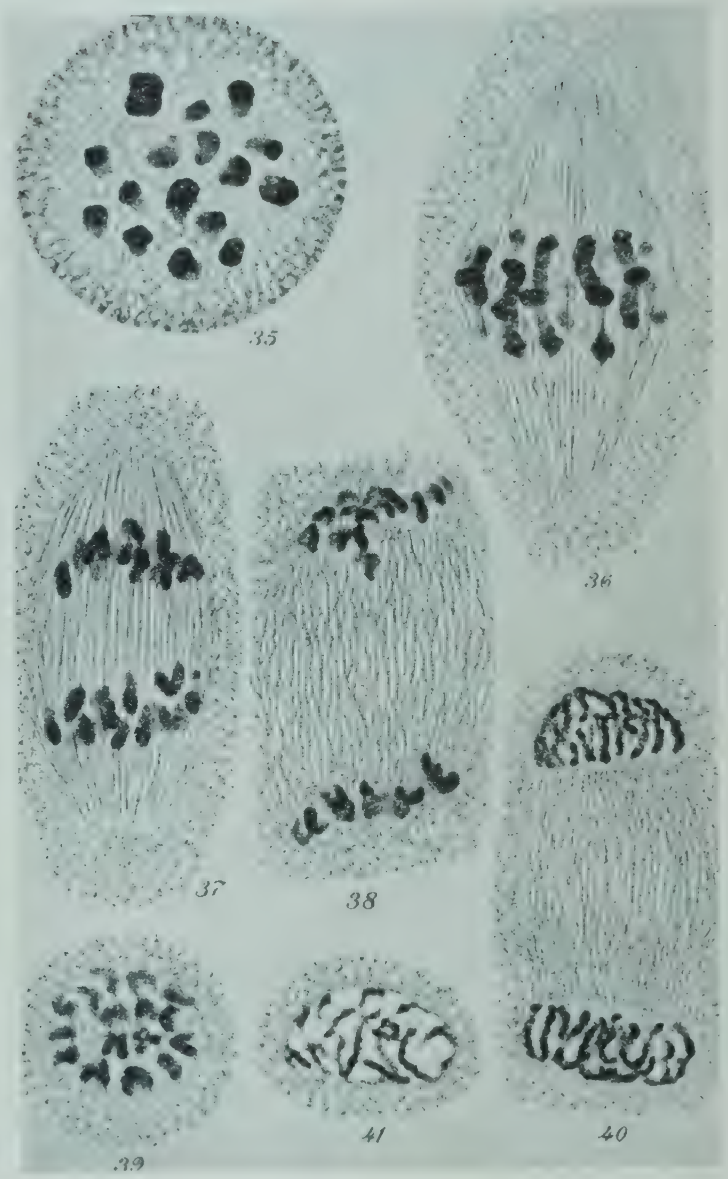


Fig. 22.

Cytological story of *Cocos nucifera*
(After Santos, 1929)

27 *A tangential section of the nucleus, a slightly older stage than 26, showing X, O, Y and V shaped chromosomes.*

28 *Three bivalent segments in the same stage as 27 under higher magnification showing Y, U and X shaped chromosomes.*

29 *A tangential section of the nucleus showing the appearance of the bivalent chromosomes after a greater condensation; shortening and thickening have taken place.*

30, 31 *Two diakinetic stages, one closely following the other. The bivalent chromosomes appear as dumb-bell shaped and as straight and bent rods.*

32, 33 *Another two successive stages of the late diakinesis, showing the formation of the multipolar spindle fibres.*

34 *Spindle fibres becoming bipolars and the bivalent chromosomes are moving toward the equatorial region.*

35 *A polar view showing the sixteen bivalent chromosomes at the equatorial plate.*

36 *Side view of the metaphase of the first division.*

37 *Typical side view of anaphase in which the daughter chromosomes are mostly V and J shaped with apex of V and J attached to the spindle.*

38 *Early telophase of the heterotypic mitosis.*

39 *A somewhat oblique view of the same stage as 38. The daughter chromosomes are mostly V-shaped.*

40 *A typical heterotypic telophase showing the elongation of the daughter chromosomes, their splitting and the formation of the clear spaces between them.*

41 *A later stage of one of the daughter nucleii in the heterotypic telophase after the appearance of the nuclear membrane.*

The effect of cultivation and manuring on the production of female flowers

Cultivation and manuring also affect the production of female flowers. The differential response to cultivation and manuring by different types of trees is also evident in the case of female flower production. The following table shows that the poor bearers are benefited most by manuring and cultivation:

Table 18.—Effect of cultivation and manuring on female flower production

Type	Percentage increase in the production of female flowers
Good	6·5
Medium	19·9
Poor	33·3

Seasonal variation in the production of female flowers

There is much variation in the number of female flowers produced during the different months. This difference is partly due to the differences in the number of spadices opened in the different months. But when the average numbers of female flowers per spadix are compared, similar differences are also noticeable. From Table 19 it is clear that, at Nileshwar-I a very low number of female flowers is produced during September to January, the flower production in December being as low as 1·67 per cent of the total flowers produced in the year. It is generally high during the months of March to May, the highest being in May. Marechal (1928) reports that the dwarf palms in Fiji produce more female flowers during November to March.

When however, the average number of flowers per spadix is taken into consideration, the highest production is found in the months of May and June at Nileshwar-I, and during the summer months of March, April, May and June at Kasaragod. There appears some variation in the monthly production of female flowers in different years, e.g., the production of female flowers was the highest in March 1934 and in June 1933 at Kasaragod.

Table 19.—Monthly variations in the production of female flowers

Months	Kasaragod — Block VIII						Nileshwar-I		
	Average number of female flowers per tree	Average number of female flowers per spadix	Percentage production to the total in the year	Average number of female flowers per tree	Average number of female flowers per spadix	Percentage production to the total in the year	Percentage of female flowers produced to the total in the year	Average per spadix	Percentage of female flowers produced to the total in the year
	1933			1934			1933		1934
January	20·6	20·0	6·6	21·6	21·8	7·0	2·2	6·4	2·7
February	28·6	28·5	9·2	28·8	32·7	9·4	9·5	10·2	4·1
March	32·5	26·6	10·5	38·0	43·0	12·6	15·1	9·3	17·1
April	44·5	32·3	14·3	45·2	35·3	14·7	12·5	10·7	17·2
May	33·4	31·9	10·7	40·2	34·6	13·1	16·7	15·2	18·9
June	33·2	34·0	10·4	26·6	28·0	8·7	11·4	15·1	7·0
July	30·5	27·2	10·0	20·6	25·0	6·7	11·1	12·3	4·0
August	21·4	22·1	6·9	19·0	23·7	6·2	8·8	10·6	4·5
September	19·4	20·7	6·2	20·4	22·7	6·7	5·4	8·7	6·6
October	20·6	18·7	7·1	16·6	19·1	5·2	2·5	7·8	6·4
November	13·7	15·2	4·4	14·7	17·9	4·7	2·9	6·9	3·7
December	11·5	13·0	3·7	15·4	15·2	5·02	1·7	6·1	0·7

Taking more or less the same type of trees, i.e., trees which have produced twelve leaves in a year and having one opened spadix in each of their axils, the average number of female flowers per spadix has been worked out in Table 20. Out of a group of 100 trees at Kasaragod only six trees conform to the above specifications.

Table 20.—Seasonal variation in the production of female flowers in the trees that produce one leaf and one opened inflorescence every month

Months	Number of leaves emerged in a year	Number of opened spadices in the year	Average number of female flowers per spadix	Percentage production of female flowers
January	12	12	28·2	10·0
February	12	12	25·5	8·9
March	12	12	26·5	9·3
April	12	12	28·5	10·0
May	12	12	32·2	11·3
June	12	12	30·2	10·5
July	12	12	24·8	8·5
August	12	12	20·3	7·0
September	12	12	19·5	6·8
October	12	12	18·0	6·2
November	12	12	16·5	5·7
December	12	12	18·2	6·2
Mean ..			24·0	

The data for this group indicate the effect of season on the production of female flowers in a homogeneous group of trees. Here also the production of female flowers is low for September to January and it is the highest during June to July. Thus it may be inferred that the production during February to July is high. The number of female flowers for the bunches which open during February to July is high. This is probably due to the adverse effect of the season at the time of the differentiation of the ovary and the perianth. It has been previously mentioned that the first differentiation of the ovary and perianth from the primordium of the female flower takes place about six to seven months prior to the opening of the spathe. In other words, the first differentiation of the ovary in the spadices which open during February to July takes place in the rainy months when no drought is experienced by the trees. The differentiation of the ovaries of the spadices which open during August to December takes place during the dry months of February to June.

Development of the female flower

The development of the female flower has been studied in some detail by Juliano (1926) and Patel (1938). According to the latter, the primordia of the female flowers are distinct even when the male flowers have not made much advance of the initial growth when the rudimentary inflorescence including the spathe is as small as 2·1 cm × 2·3 cm. Juliano observed that the female flowers arise at the axils of tertiary bracts which are tiny, collar-like structures at the very basal portion of the flowers and are hardly distinguishable after the maturity of the pistils. He observed that the female flower is enveloped by small scaly bracteoles or prophylls which enclose inside six perianth lobes, the outer sepals and the inner petals, surrounding the spherical pistil (Fig. *24*: *2*). The ovary is tricarpous (Fig. *24*: *3*) and each carpel is found to possess a single ovule (Figs. *24*: *3* & *4*). He found that only one ovule develops later and the other two either abort or degenerate. The stigmas are sessile. He found two or three floral primordia arising simultaneously from the axil of a tertiary bract. If only a single female flower develops, the male flowers around it degenerate (Fig. **24**: *1*). Nearly all the cells of the undifferentiated outgrowths are isodiametric and the mode of development of the floral organs is centripetal (Fig. **24**: *5-8*). At the axil of the tertiary bract and the floral cone, two scale leaves appear as two small papillate protrusions which elongate, bend and cover the juvenile flower (Fig. **24**: *5*). He also observed that as soon as the bracteoles develop, the three sepals develop simultaneously from the basal portions of the flower primordium, one overlapping the other towards the apex (Fig. **24**: *6* & *7*). The sepals elongate pushing their way between the bracteoles and the floral cone, and the petals which alternate with the sepals emerge simultaneously (Fig. **24** : *7*), first as rudimentary papillae, but soon differentiating into scale-like structures like sepals (Fig. **24**: *6*). The petals do not develop as much as the sepals. The next to develop is the aril (Fig. **24**: *8*), the carpels developing and maturing last (Fig. **24**: *7* & *8*).

On removal of the floral envelopes, Juliano (1926) observed around the apex of the pistil and near the stigma some powdery white material, which when scraped and mounted on a slide, is found to consist of multicellular scales consisting of numerous thin-walled cells, the free ends of which are round. He also found enclosed among them, large, round, more or less spheroid cells containing raphides. Mobius (1905) observed the scales only on the young female and unopened flowers while Juliano observed them not only on the juvenile female flowers, but also on the juvenile rachis and rachillae and all over the spathes. He also found them persistent around the stigma of the young fruit which disappear only when the fruit matures.

Juliano observed that the ovules have already developed within the thick carpel wall when the inflorescence emerges from the inner spathe. Each ovule is found to possess two coats (Figs. **24** : *4* & *9* ; **32**: *15*). The conducting tissue, extends from the stigmas and is composed of palisaded cells. This tissue trifurcates as it passes down to the loculi or cells of the ovary. The anatropous ovule completely fills each of the loculi. He observed that the ovary comprises three ovules all of which are anatropous which is in conformity with the observations made by Winton (1901).

Development of the ovule

The development of the ovule in the coconut has been traced by Quisumbing and Juliano (1927). According to them when all the floral envelopes (sepals, petals, aril and carpels) and carpel walls have been formed and differentiated, the main axis of the flower starts as a papilla and commences to enlarge, gradually becoming prominent at the basal portion of the ovarian cavity (Fig. **28** : *1*). This protuberance, according to them, consists of an epidermal layer of cells, most of which are square to rectangular, with their long axes tangential to the periphery. The hypodermal cells are observed by them to be isodiametric filled with plenty of protoplasm and large nuclei. They also found, that their growth keeps pace with that of the carpel walls. As the main axis enlarges, the epidermal and hypodermal cells divide and elongate periclinally and their cytoplasmic contents become less thick than those at the sides, which give the axils a pyramidal appearance (Fig. **28** : *2*). Simultaneously with the elongation of the cells at the apex, the basal cells at the sides divide periclinally at first, and division rather than elongation is their first activity. They found that by repeated periclinal divisions of the cells at the sides, and radial elongation and enlargement of the cells at the apex of the axis of the flower, the basal lateral sides are pushed into the three loculi of the carpel walls. These protuberances, which at first are slight, constitute the nucellus (Fig. **28** : *3*) of the ovules. They also observed, that by one-sided growth, each primordium becomes bent towards the base of the ovary, developing into anatropous ovules. The nucellus, first appears as a few-celled papillae with projections from which the integuments develop (Fig. **28** : *4* & *5*).

They observed, that the hypodermal cells of the nucellus then divide periclinally and anticlinally. The activity of that mass of tissue is responsible for the enlargement of the nucellus, which remain squarish and become comparatively smaller than the hypodermal cells which in their juvenile stages are nearly identical in size. The anticlinal division of the epidermal cells enable them to keep pace with the increasing nucellar tissue.

According to them, the integuments do not begin to appear until after the inflorescence has attained a maximum circumference of 15 cm to 18 cm (measured with the inner spathe still attached). They observed the inner integument (Fig. **28** : *4*) is the first to develop and is followed by the outer (Fig. **28** : *5*).

Development of the embryo sac

The nature of development of embryo sac in the coconut has been studied by Quisumbing and Juliano (1927).

According to them, the ovule attains a considerable size with its integuments fully differentiated before the archesporial cell becomes evident. The archesporial cell becomes the megaspore mother cell and enters synapsis after two integuments have long been evident. At first the megaspore mother cell is apparently undifferentiated from the surrounding cells, but soon it becomes grumous and is then readily distinguishable (Fig. ***29*** : *6* & *7*), from the rest of the nucellar tissue by its size and great staining power. The presence of a large nucleus and its richness in cytoplasm makes the megaspore mother cell more prominent which is apparent after the inflorescence has emerged from the outer spathe, and while still enveloped by the inner spathe. They observed that it is more or less square with the nucleus at the centre of the embryo sac (Fig. ***29*** : *6*) to begin with, but soon elongates with its micropylar portion enlarged (Fig. ***29*** : *7*). The mother cell usually appears at the third layer of cells of the nucellar tip, but sometimes is deep seated at the fourth or fifth layer. As the cells enlarge and elongate, a definite migration of the nucleus to the micropylar end is observed. They also observed later vacuolation of the one-celled embryo sac becoming apparent as the sac enlarges. The cytoplasm is denser towards the micropylar portion of the cell and vacuolated at the chalazal region. They found only one archesporial cell developing while Bauch (1911) observed two, one of which only became functional.

Tracing the development of the archesporial cell, they observed it to elongate and increase in size, always maintaining the bulbous and bulging appearance and becoming wider at the micropylar end, the chalazal end being somewhat narrow. More granular bodies appear to accompany the enlargement of the nucleus. The vacuoles enlarge in the nucleus and the granular bodies appear in the net work of protoplasm. They found later within the nuclear membrane, a net work of fine dotted threads partially meshed by granular substance. They also observed the " slenderspireme " (Fig. ***29*** : *8*) indicating the first stage of the approaching division. The threads become thicker and their dots larger while the nucleolus still remains prominent. Before finally passing into the contracted state, it was noticed that the threads begin to close round the nucleolus after which the nucleus entered the period of synapsis in which state it remains for some time.

They observed the nucleus of the megaspore mother cell dividing into two more or less unequal sizes, without wall formation (Fig. ***29*** : *9*) taking place before the emergence of the inflorescence from the envelope of the inner spathe. The formation of the tapetal cell and the four megaspores is eliminated as the two daughter nuclei lie side by side which are vacuolated and in early synaptic stage of division. They found more granules in the cytoplasm of the sac, at which stage the sac shows signs of disintegration and absorption of the nucellar cells, which begins at the chalazal region (Fig. ***29*** : *9* & *10*). Since the formation of tetrad is eliminated, this first division of the megaspore mother cell is heterotypic in nature. It was not possible for them to count the number of chromosomes in the first division of the megaspore mother cell.

No polarity is observed at the binucleate stage of the sac. The vacuolation begins at the micropylar and chalazal ends, and the daughter nuclei are at the centre of the sac. They found marked similarity in shape between the chalazal nucleus as well as the micropylar nucleus, although, the chalazal nucleus seems to be more advanced in development (Fig. ***29*** : *9*).

At the quadri-nucleate stage of the sac they found the polarity in full display (Fig. ***29*** : *10*). The four daughter nuclei are at the ends of the sac, two at the micropylar end, and the other two at the chalazal end. The two chalazal nuclei, are unlike in size, the one near the centre of the sac being slightly larger. They observed the surrounding nuclear cells undergoing disintegration, and their nuclei are freely liberated in the sac. Vacuoles are noticed to be larger at the centre of the sac, and cytoplasm is thickest at the two ends and the nuclei are at rest at that period.

When the sac reaches the octo-nucleate stage, the enlargement of the sac has gone far enough. They observed, that all the chalazal cells show great depletion, almost to the micropylar end (Fig. ***30*** : *11*) which makes the nuclei appear to be at the centre of the sac. The micropylar group, consists of three nuclei of the same size, one of which is the polar nucleus (*pn*). The larger one is the egg (*e*) and the two similar ones are the synergids (*sy*). The chalazal group consists of three congregated antipodals (*an*) and the elongated polar nucleus. It seemed evident to them, that the polar nucleus from the chalazal region is much larger than that from the micropylar region. They found the antipodals migrating to the chalazal pole and disintegrating before the fusion of the polar nuclei. The union of the two polar nuclei (Fig. ***30*** : *12*) is accomplished by the motility of the two nuclei approaching each other, and meeting and coalescing near the centre of the embryo sac. They believed that the polar nucleus of the chalazal region is apparently at rest and the micropylar one appears more motile. They observed the coalescence taking

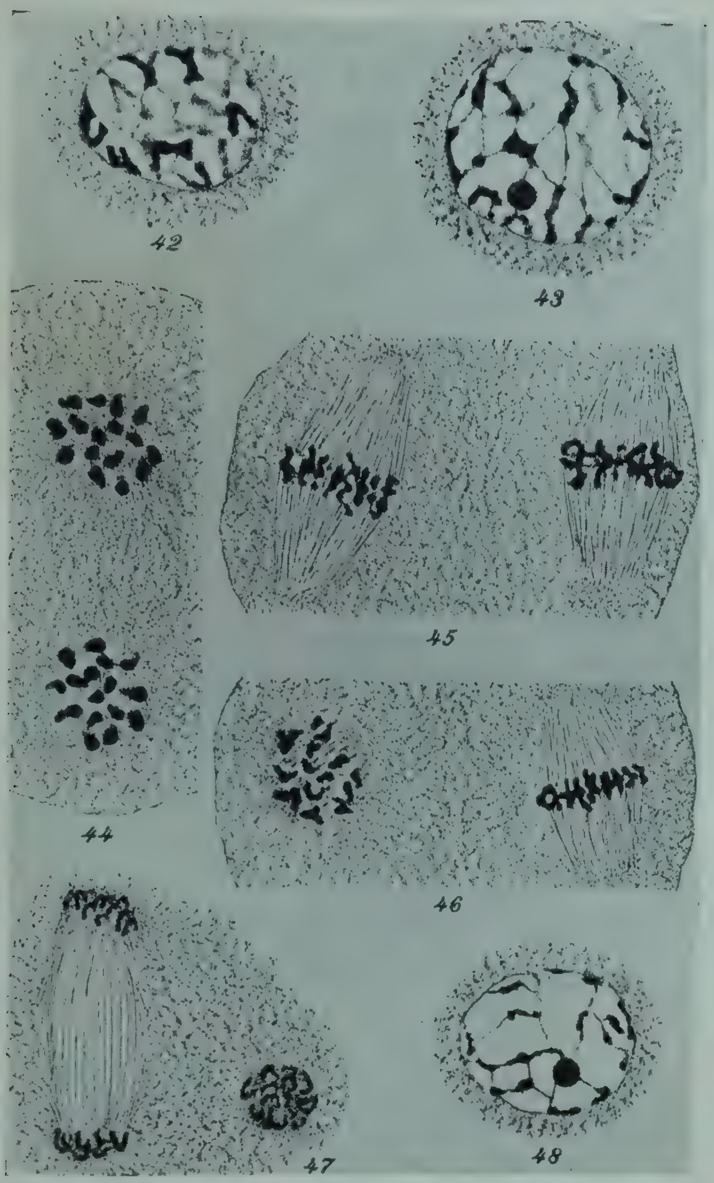


Fig. 23. Cytological story of *Cocos nucifera*
(After Santos, 1929)

42, 43 *Two stages of the daughter nuclei, indicating the very irregular shape of the daughter chromosomes apparently going to resolve, but remaining more or less in this condition for a short period and not passing to true resting stage.*

44 *A polar view of the daughter chromosomes at the metaphase stage of the homoeotypic mitosis.*

45, 46 *Two views of homoeotypic metaphase.*

47 *A homoeotypic telophase, showing the side view of the future grand daughter nuclei.*

48 *A grand daughter nucleus after appearance of the nuclear membrane and the nucleolus.*

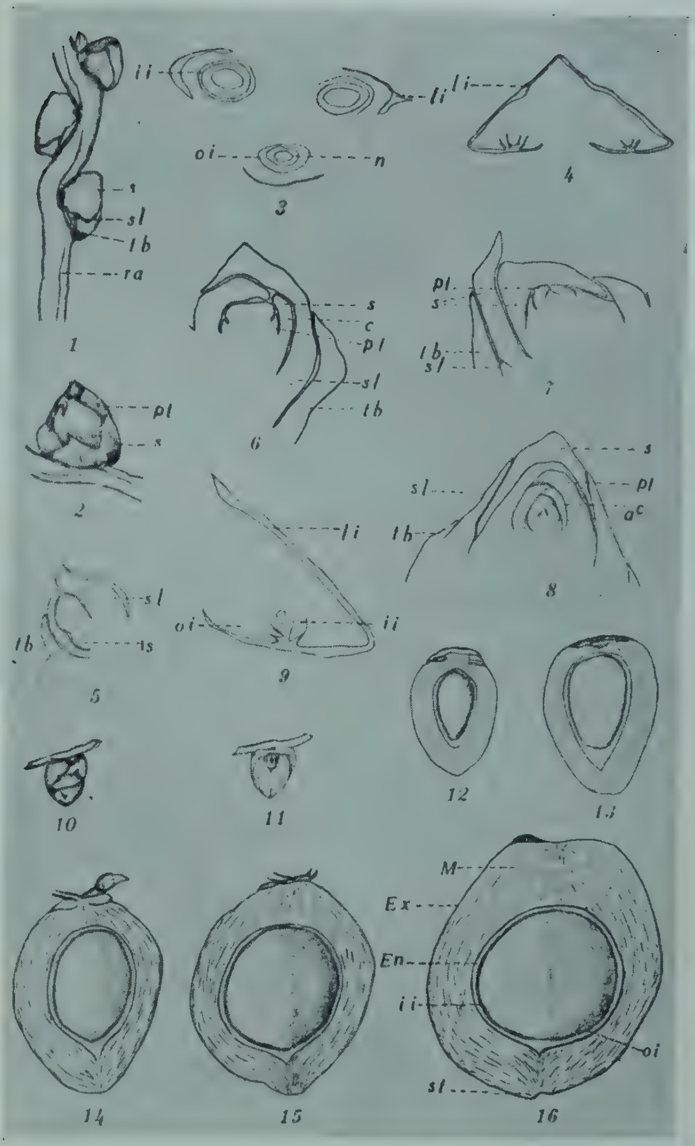


Fig. 24. Development of the fruit
(After Juliano, 1926)

1 *A portion of the base of the rachilla showing three developed female flowers with the lateral male degenerated flowers darkened.*

2 *Lateral view of the female flower showing petals* (pt) *and sepals* (s).

3 *Cross-section of the ovary to show the position of the ovules. Inner integument* (ii), *outer integument* (oi), *nucellus* (n).

4 *Longitudinal section of the ovary to show the anatropous ovules.*

5 *Longitudinal section of the young female flower showing the two scaly leaves* (sl) *and the beginning of the sepals* (s).

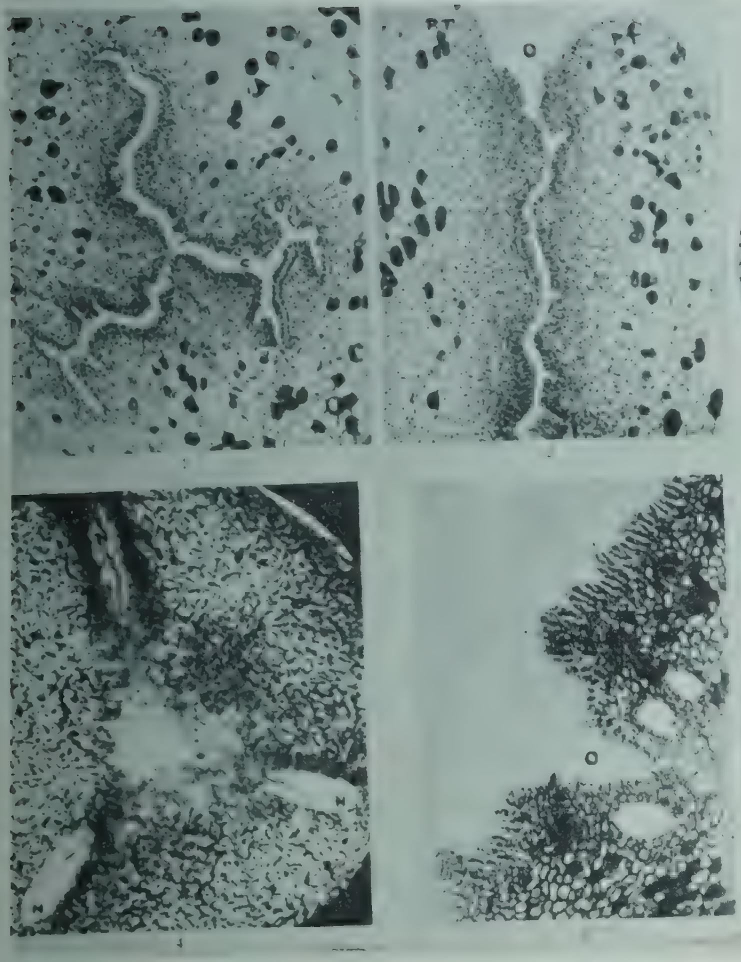
6 *Longitudinal section of an older female flower with tertiary bracts* (tb), *scaly leaves* (sl) *and petals* (pt) *developing.*

7 *Longitudinal section of a much older female flower showing the perianth segments already developed.*

8 *Longitudinal section of a female flower with aril* (a) *and with carpel* (c) *walls already formed.*

9 *Longitudinal section of one of the anatropous ovules, showing the outer and inner integuments.*

10-16 *Diagrammatic drawing, showing the development of the fruit.*



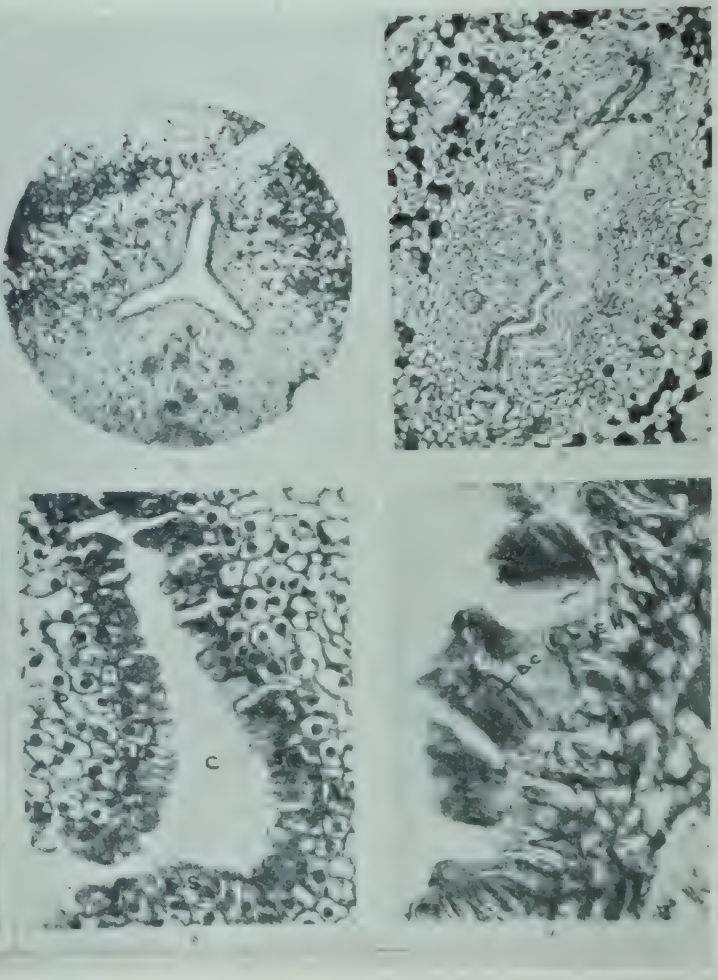


Fig. 25. Septal nectaries of male flower **Fig. 26. Septal nectaries of female flower**

(After Narayana, 1937)

1 *Transverse section of pistillode showing three septal nectaries meeting in the centre* (c) *cavity.*

2 *Longitudinal section of pistillode showing one nectary with the outlet* (o) *between the pistillode teeth* (PT).

3 *Transverse section of part of ovary at the time of secretion showing orifice* (o) *and epidermal hydathodes.*

4 *Transverse section of ovary showing three septal nectaries* (N).

5 *Transverse section of ovary showing the central triradial canal.*

7 *Transverse section of a septal nectary of the ovary* (C) *Cavity;* (SS) *Secreting surface;* (P) *parenchyma of the nectary.*

8 *Transverse section of part of septal nectary of ovary;* (C) *cavity;* (SS) *secreting surface;* (P) *parenchyma.*

9 *Transverse section Ovary* (part of) *below stigma showing epidermal hydathodes* EH *and bundles* broken, *of crystals* (BC).

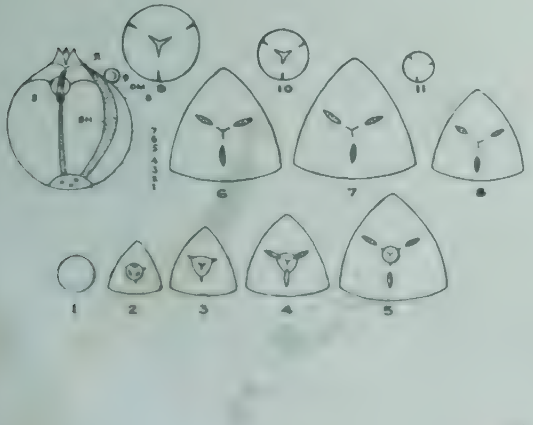


Fig. 27. Ovary-diagrammatic representation of the course of the septal nectaries

(After Narayana, 1937)

place before fertilisation and before the pollen tube tip has reached the embryo sac. At the final orientation of the component parts of the sac, the micropylar nucleus tapers at both ends and becomes more enlarged at the middle. In the mature embryo sac, the three antipodals at the chalazal end are surrounded by the protoplasm and are faintly recognisable (Fig. ***31*** : *13*).

The egg apparatus at the micropylar end is derived from the nuclei at the micropylar group. The egg is already differentiated from the two synergids (Fig. ***31*** : *11*) prior to the migration of the polar nucleus and becomes greatly vacuolated and enlarged and inserted somewhat lower down in the walls of the embryo sac.

In the complete embryo sac (Fig. ***31*** : *13*), the antipodals have gone into progressive degeneration and endosperm nucleus (*en*) has assumed a central position with a massive nucleolus with a spherical form. The egg apparatus consisting of a very prominent egg (*e*) and two synergids (*sy*) are also observed to have approached maturity at which stage the synergids begin to show signs of degeneration.

Development of nectaries

Secretion of nectar by glands situated in the male and female flowers of the coconut has been recorded by Huggins (1928) and Narayana (1937). Patel observed secretion of nectar from three nectaries and the pores found at the base of the teeth of the pistillode of the male flower. Sampson (1923) observed sticky viscous surface in the tri-radial opening at the base of the ovary and their direct opening near the apex of the fruit coat through which honey is secreted. Marechal (1928) has recorded the secretion of sugary fluid from the numerous pores situated around and below the stigma. Narayana has studied in detail the morphology of the nectaries in the male and female flowers and has recorded certain differences in the nectaries present in the male and the female flowers.

The honey in the male flowers, according to Narayana, is secreted by three intercarpellary or septal glands of the pistillode. These glands are narrow, short and free at the base of the pistillode, but meet a little way up in the centre and appear like one entire structure with three radiating branches corresponding to the three carpels of the pistillode (Fig. ***25*** : *1*). The secretory surface according to him consists of a closely packed palisade like cells with rather large nucleus, dense, granular cytoplasm and thin-walls. The glands increase in breadth radially and extend upwards to the bases of the pistillode teeth where they open between the teeth (Fig. ***25*** : *2*) in the tri-radial orifice of the pistillode.

The stigmatic region emerges out of the perianth lobes as the female flowers become receptive and a sweet fluid collects at the inner surface of this region. Narayana in studying these, observed three orifices 1 mm long and each of these (Figs. ***27*** : *9*. ***25*** : *3*) is a minute opening alternating with the stigma. When the secretion commences, a large drop of nectar is collected at each of these three orifices, which oozes out from three different centres within the ovary (Fig. ***25*** : *4*). He observed each secretory area to be situated in between the margins of the carpels in a line with each of the arms of the central radial canal (Fig. ***26*** : *5*). The secretion according to him is most profuse midway between the stigmas and the base of the ovary and is very scant in the region of ovules and in the region between the stigmas and orifices while it is completely absent at the base of the ovary below the ovules.

Narayana traced the course of the septal glands (Fig. ***27*** : *1* to *11*). The glands according to him are like a canal or duct branched and compressed laterally and is narrow at the upper and lower extremities and broad about the middle (Fig. ***27***). The glands take a very superficial course near the orifice and form slightly swollen streaks on the pericarp extending to the stigma. The gland is lined with closely packed palisade-like secreting cells as in the male flower and surrounded by a tissue of parenchyma (Fig. ***26*** : *7* & *8*). The nectar from these glands oozes out through the three orifices. Stigmatic secretion which is effected by epidermal cells of the inner face of the stigma according to him starts a little earlier than that of the septal nectaries.

He observed that the tri-radial canal (Fig. ***26*** : *5*) in the centre of the ovary where the three carpels meet and which extends from the stigma to the ovule-bearing region at the base of the ovary does not appear to take part in the secretion. He discovered a number of closely packed needle shaped crystals (calcium oxalate) in shallow depressions on the epidermis and these depressions are provided with secretory cells (Fig. ***26*** : *9*) which exude a liquid which on drying shows incrustations of crystals. The inner tissue of this region, according to him, is made up of a mass of parenchymatous cells with a number of scattered young vascular strands without any secretory elements and the epidermis consists of closely packed, conspicuously elongated cells belonging to the category of trichome type of multicellular hydathodes, each consisting of a group of 4 to 16 cells with a narrow base, a round head and a thick outer wall.

Secretion of honey

When the stigmas are receptive, a clear sweet fluid is profusely secreted in four places, viz., at the base of the stigmas and at the three pores on the pericarp towards the top of the ovary. These pores are the outlets of three intercarpellary secreting channels which are provided with honey-secreting cells within. The channels extend beyond the pores and meet at the base of the stigmas where there is a cushion-like structure. It has a pale outer coat at the time of stigmatic receptivity and looks like a gland. There are no honey-secreting glands at the base of the ovary as Sampson (1923) has reported and what he calls the ducts of the glands are actually the intercarpellary canals which themselves secrete honey.

THE FEMALE PHASE

The female phase which is the interval between the receptive stage of the first female flower and the last female flower has also been observed to vary according to the condition of the tree. But generally, it is much shorter than the male phase and extends for four days to a week, depending on the nature of the tree, locality in which it is cultivated, the season of the year and the number of female flowers borne on the inflorescence. Liyanage (1951) observed this to last for 5 to 7 days in the tall palms and 10 to 16 days in two other types, viz., dwarf of the Malayan origin and the King Coconut.

The receptivity of stigma

About three weeks after the opening of the spathe, the female flowers in an inflorescence commence to open. As in the case of the male flowers, the female flowers at the top of the spadix are the first to open. The female flower, when it opens, is little more than double the size of what it was on the opening of the spadix. Its volume at this stage varies from 10 cc to 22 cc with a mean at about 16 cc. The stigmas are very white and remain so, for one or two days. After this period, the secretion of the nectar commences and the stigmas become receptive. The period during which the female flowers remain receptive varies from one to three days. There is slight variation in the period during which the stigmas are receptive in the different coconut growing countries. At Kyala and Peradeniya in Ceylon, it is 24 hours, while in Los Banos in the Philippines, it varied between two to three days (Patel, 1938).

Interval between male and female phases

The interval between the end of the male phase, and the beginning of the female phase, has an important bearing on the nature of pollination. If there is an interval, cross pollination might be common. The observations made by Patel for a group of 68 trees for a year showed that when the interval is nil, there may be chances for self pollination. In 34 per cent and about 29 per cent of the trees, the commencement of the female phase was respectively on the 20th and 22nd day after the opening of the spathe and the average interval between the end of the male phase and the commencement of the female phase was 2·6 days. Only in 1·69 per cent of the trees the interval was nil.

Frequency of opening of the spadices in different months according to the intervals between the end of the male phase and the commencement of the female phase recorded by Patel show that during March, October and February there was practically no chance for self fertilisation. During July and August, April and January there was no interval in a fair number of trees and the monthly mean intervals varied from month to month and were low for September and November and fairly high for January, May and June.

It may, therefore, be concluded that in most of the cases, staminate flowers fall off before the pistillate flowers of the inflorescence become receptive. This is, however, not the case for the dwarf type of palms in which the male flowers in the same inflorescence continue to open, when the female flowers are receptive, thus facilitating self pollination. Observations by Jack and Sands (1922) showed that in Malaya the female phase in dwarf palms not only began, but frequently ended before or at the same time as the male phase, thus making self pollination the rule instead of a chance. They pointed out that within four days after completion of the male phase, the male flowers of the succeeding inflorescence opened. The average duration of the male phase was 21 days and that of the female phase 8 days. In about 90 per cent of the cases female phase ended with or after the male phase, but the end of the female phase was never more than three days behind the end of the male phase. Only in five per cent of the inflorescence was there any overlapping observed.

Pollination

There is considerable difference of opinion among workers as to the nature of pollination taking place in the coconut. Some workers believed that it was allogamous or wind-pollinated, while others maintained that it was insect pollinated. According to a few others it was essentially a cross pollinated plant through the agency of wind and insects. Yet some others showed that self-pollination was of common occurrence in the coconut.

Federico (1865) in his classification of plants according to the mode of fertilisation of the flower included the palms under the class *Anemophillae* with immobile flowers (typus *immoti-florus*). This theory was supported by Kunth (1909). This also appeared not improbable considering the fact that the morphology of the flower presented several features of essentially wind pollinated plants, *viz.*, lack of showy parts, bright colour, sticky and rough-surfaced pollen, etc. The production of a large quantity of pollen, a distinct exposure of anthers and stigma to the air designed to scatter the pollen to the wind, the three pointed stigmatic teeth standing erect at the stage of fertilisation, its complete separation of sex with staminate and pistillate flowers distributed separately in the same inflorescence are other factors to facilitate cross-pollination. The fact that the female flowers in the coconut generally attain receptivity some time later than completion of the period of anthesis of the staminate flowers also provides evidence in this direction. Patel observed that when slides smeared with vaseline and exposed for 24 hours at about the height of the palm, they collected about 24 pollen grains on a square cm and he, therefore, believed that it was not altogether safe to conclude that wind does not at all take part in pollination.

The peculiar structure of the flower and the presence of honey glands led Sampson to believe that nature has intended that the coconut should be pollinated by the aid of the insects. Furtado (1924) suggested that the groove present in the pollen indicated that the pollen belonged to the type adapted to be carried by insects. Aldaba (1921) working in the Philippines, showed that very little pollen is carried by wind from one tree to the other and that pollination is chiefly effected by insects, the most important among them being the house fly (*Musca domestica*), several species of *Lasila* (Diptera) and *Apis indica*. According to Hunger (1920), bees, flies and bugs are agents in pollination. Furtado (1924) gave a list of other more and possible agents in coconut pollination. Patel showed that the black ant — *Camponotus compressus* played an important role in the pollination of the coconut. As estimated by him, each ant carried about 40 to 50 pollen grains and he pointed out the probability of these carrying pollen from one inflorescence to another on the same tree. Furtado also showed that ants played an important part in the pollination of the coconut. Petch (1913) in Ceylon on the other hand stated that the ant is to be excluded from the work of pollination since the liquid collected below the stigma of the flower kept the ants away. Huggins (1928) maintained that both insects and wind are pollinating agents. Coombs and Cookson (1917) observed that the coconut was insect pollinated besides being dependent on wind for pollination.

Extent of cross-pollination

To determine how far cross-pollination takes place, Patel cited an experiment in which the seedlings from the self-pollinated and naturally pollinated trees were grouped into green, yellow and red according to the colour of the petiole. He applied the test of independence to the data and the progenies of the naturally pollinated and selfed trees were compared as in the table below:

Table 21.—Segregation of progenies for petiole colour

Petiole colour of mother tree	Particulars of crosses	Number of seedlings with petiole colour		
		Green	Yellow	Red
Yellow	Selfed	10	22	7
	Naturally pollinated	12	39	7
	Expected number of naturally pollinated* ..	15	33	10†
Green	Selfed	10	18	1
	Naturally pollinated	16	21	4
	Expected number of naturally pollinated ..	14	25	2‡

* Expected number of naturally pollinated seedlings is calculated in the same ratio distribution as the selfed one.

† P lies between 0·3 and 0·2.

‡ P lies between 0·5 and 0·3.

He observed from the data that the differences in the segregation consequent on the method of pollination were not significant since the value of x^2 is very much reduced and the value of P is fairly high. He, therefore, concluded that self-fertilisation was common.

In most of the cases, the staminate flowers fall off before the pistillate flowers become receptive. In a few trees, and particularly in January, April and August, there is the possibility for self-pollination through overlapping of spadices. The coconut is, therefore, not entirely cross-pollinated as is generally supposed. There are fair chances for self-pollination in April.

The chances of inter-spadix pollination

It is just possible that the male phase of the succeeding spadix will commence before the completion of the female phase of the preceding spadix. In that case there is the possibility for self-pollination through the overlapping of the spadices. During the summer months, a large number of spadices open and the interval between the opening of the two successive spadices is also short. Patel observed that the chances for inter-spadix pollination in a year are for about 22 per cent of the total number of spadices opened, the maximum chances being in the months of March, April and May. In April, about 8 per cent of the total spadices opened in a year have chances for inter-spadix pollination. He also noted that there was much variation in the chances for inter-spadix pollination in different months in the same tree, the minimum chances being in the months of July to February with no possibilities in November. It was also observed that there were chances for inter-spadix pollination during the month of April in about 75 per cent of the trees while in the months of March and May this chance was confined to 40 to 50 per cent of the trees. According to him the increased floral activity during the summer allowed a fair chance for inter-spadix pollination. But Copeland (1931) reported that this kind of pollination took place during the wet weather in the Philippines. Patel observed that as ants were very common on the coconut growing areas of the West Coast, the possibilities for the inter-spadix pollination must be admitted. Petch (1915) had also reported the overlapping of the inflorescences in Ceylon.

Development of the fruit

Winton (1901) and Juliano (1926) studied the nature of development of the fruit.

The latter observed that after fertilisation, the growth of the fruit follows with the pericarp developing most rapidly at the basal region which remains soft and whitish until the fruit is nearly mature. The endocarp is already differentiated as a soft, creamy, white structure long before the time of fertilisation. He observed, that as the fruit develops and matures, the embryo-sac increases in size, leaving a large vacuole at the centre. The embryo-sac is at first rounded and then it elongates and widens until near maturity. The fruit of the particular variety examined loses its conical shape (Fig. ***24*** : *2, 10* & *11*) in the early part of the elongating period and becomes spheroidal to orbicular (Figs. ***24*** : *12-16;* ***32*** : *1-5*), as it matures.

When the fruit is young, the mesocarp comprises the major portion of the pericarp, being wider near the stigmas and sides and very narrow at the portion which attaches the fruit to the rachilla. During its development, the mesocarp up to maturity increases in thickness in the region opposite the stigmas or near the micropylar end of the ovules. The exocarp always remains tough and hard and loses its green colour when old, the final colour varying with the variety. The number of fibrovascular bundles in the mesocarp observed by him increases with development, so that at maturity the fruit contains numerous fibres.

Before the ovules are formed, the pericarp wall is homogeneous in structure and is composed of isodiametric cells. As the loculi of the ovary develops, and just before the ovules are formed, the pericarp wall undergoes triple differentiation (Figs. ***24*** : *8 ;* ***32*** : *6*) and the outermost layers of cells become squarish to elongated horizontally and the hypodermal cells are isodiametric. The cells within the hypodermis are large and the innermost part of the pericarp wall is composed of small rectangular to squarish cells. The pericarp then undergoes differentiation long before the ovules are formed, into (*a*) an outer single layer of squarish to elongated cells comprising the exocarp ; (*b*) the large isodiametric cells of the mesocarp ; and (*c*) the small isodiametric cells of the endocarp (Fig. ***32*** : *8*).

By the time the ovules appear, the mesocarp cells have already undergone advanced and complete differentiation and the cells of the mesocarp which have rounded corners elongate horizontally and enlarge at the juncture of the stigmas and the ovary. He found the cell enlargement continuing downwards towards

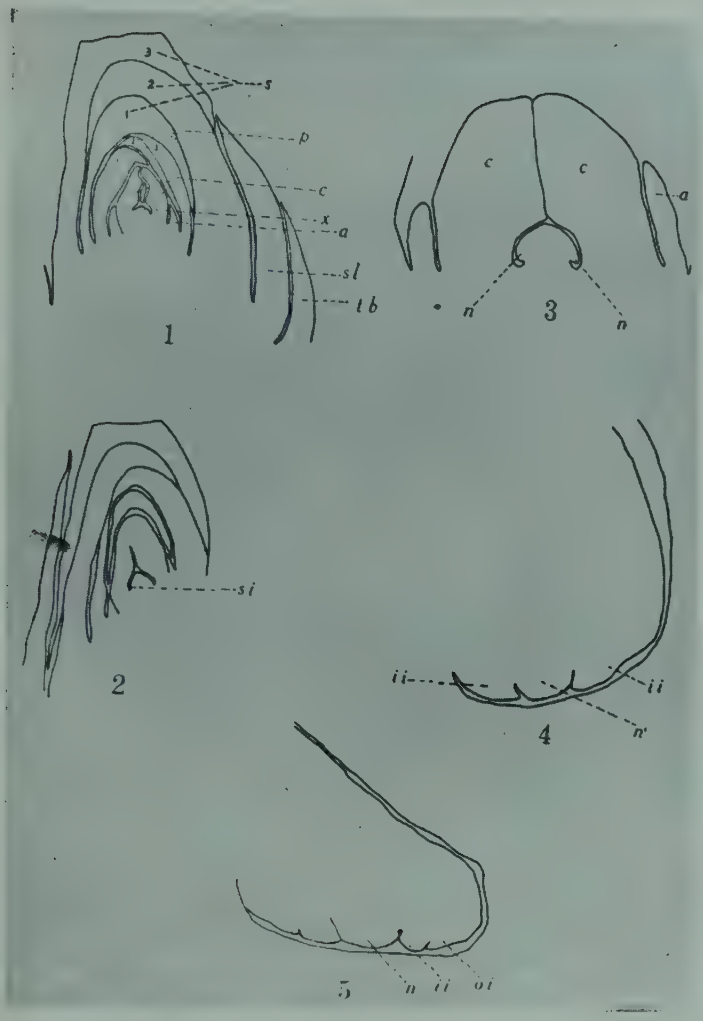


Fig. 28.

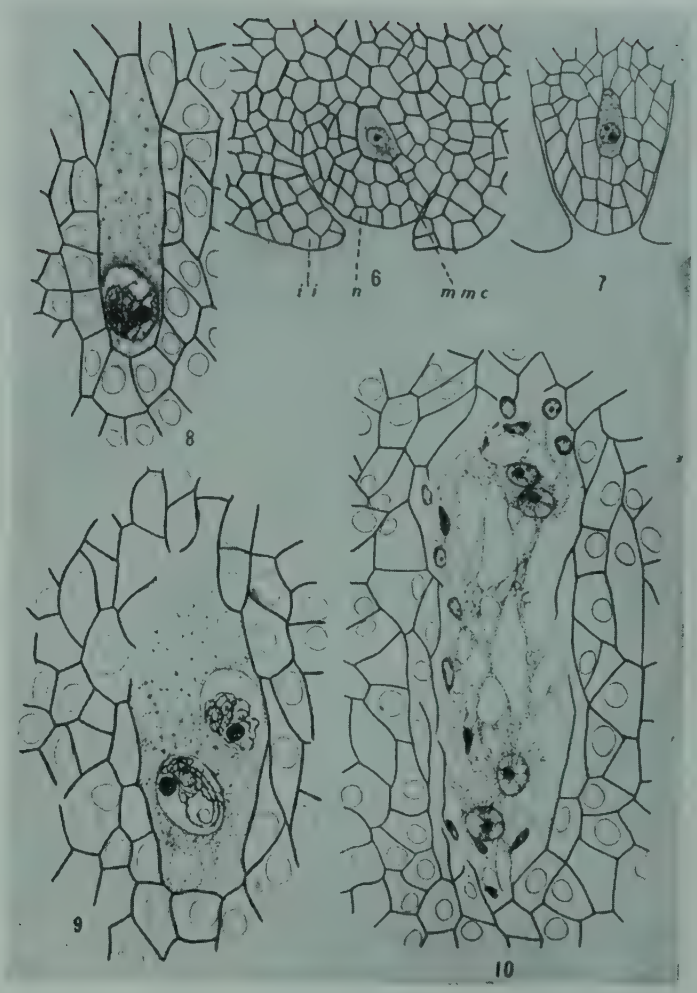


Fig. 29.

Development of ovule and embryo sac
(After Juliano and Quisumbing, 1931)

1 *Median longitudinal section of the female flower showing tertiary bract* (tb), *scaly leaves or " bracteoles "* (sl), *sepals* (s), *petals* (p), *aril* (a), *carpel* (c) *and floral axis* (x).

2 *Median longitudinal section of older flower showing pyramidal appearance of floral axis,* (si) *sides of axis where nucellus of ovule is developed.*

3 *Median longitudinal section of ovary showing beginnings of nucellus* (n) *of ovules, within carpel walls* (c).

4 *Longitudinal section of anatropous ovule with inner integument* (ii) *already developed.*

5 *Longitudinal section of much older ovule with two integuments, inner* (ii) *and outer* (oi), *appearance of latter being belated.*

6 *Longitudinal section of ovule with archesporial cell already differentiated which functions as megaspore mother cell* (mmc).

7 *Megaspore mother cell beginning to elongate.*

8 *Megaspore mother cell at synaptic stage.*

9 *Dinucleate stage of embryo sac daughter nuclei at synaptic stage. Note absorption of nucellar tissue beginning at chalazal end.*

10 *Quadri nucleate stage of embryo sac, two nuclei at micropylar end and two at chalazal end. Note destruction of nucellar tissue.*

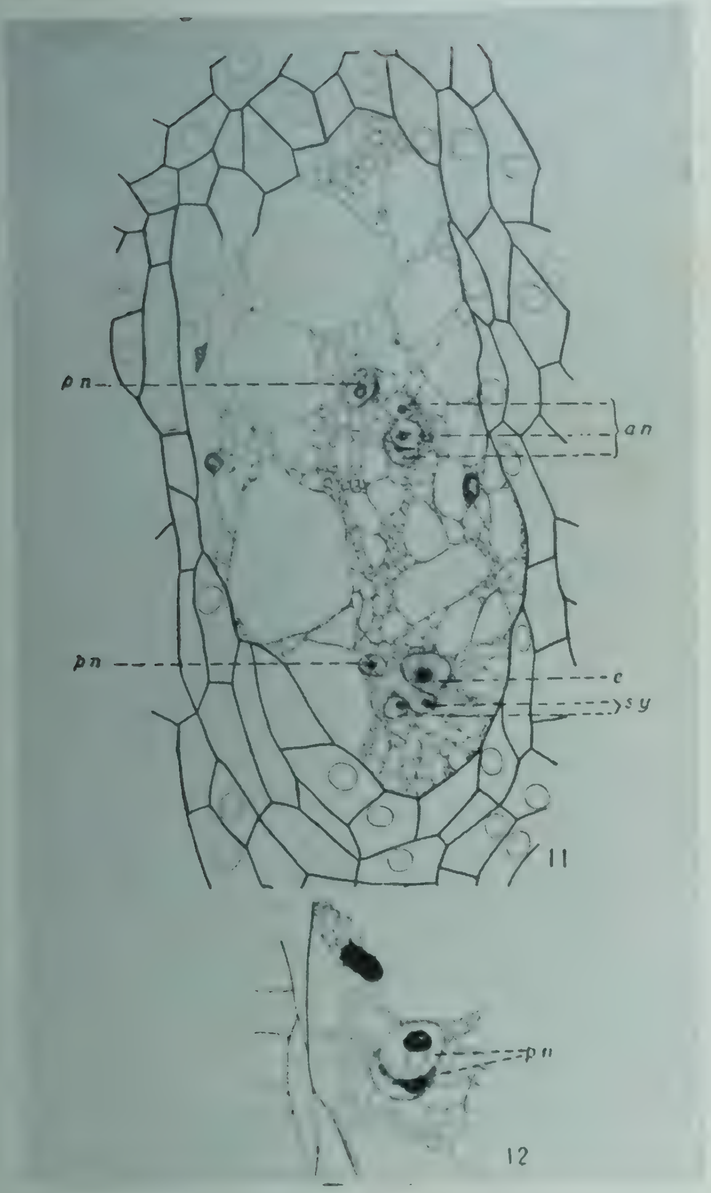


Fig. 30.

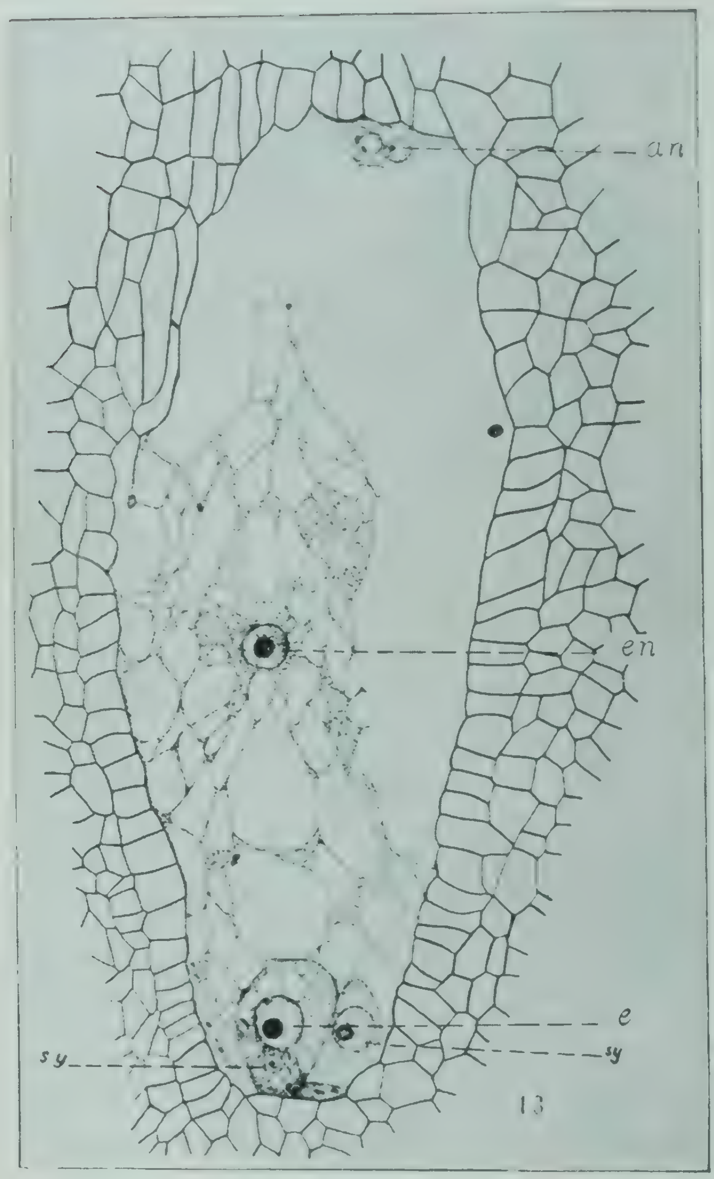


Fig. 31.

Development of ovule and embryo sac
(After Juliano and Quisumbing, 1931)

11 *Octo nucleate stage of embryo sac before final orientation of nuclei* (e) *egg,* (sy) *synergids,* (pn) *polar nuclei,* (an) *antipodals.*

12 *Fusion of polar nuclei.*

13 *Mature embryo sac showing antipodals* (an) *at process of degeneration, endosperm nucleus* (en) *already formed, and egg apparatus consisting of a prominent egg* (e) *and synergids* (sy) *at the stage of degeneration.*

the basal portion of the ovary. Simultaneously with the differentiation of the mesocarp is the appearance of the tanniferous cells, starting from the stigmas and continuing downwards. Further differentiation of the mesocarp is marked by the production of more tanniferous idioblasts soon after the opening of the inner spathe (Fig. ***32*** : *7*). He also observed that while the differentiation of the mesocarp is in progress, the endocarp cells remain isodiametric. The exocarp cells, which always remain as one layer in thickness, elongate tangentially and develop a thick outer wall (Fig. ***32*** : *6*) as they mature.

While the mesocarp undergoes differentiation, the endocarp remains as a clear, white structure in the innermost portion of the pericarp and starts its further differentiation soon after the mesocarp is differentiated. The cells have no tannin (Fig. ***32*** : *7*) and the walls towards the loculi are lined by palisaded cells from the stigmatic point downwards. Just adjacent to this single layer of palisade cells, one to three rows of horizontally elongated, more or less compressed cells are evident, which are bordered within towards the mesocarp by isodiametric cells which become larger as they approach the loculi. He also discovered juvenile fibro-vascular bundles (Fig. ***32*** : *7*) and the peripheral cells of the endocarp at the micropylar end becoming vertically palisaded and isodiametric at the hypodermis and within.

The further increase in the size of the endocarp is due to further cell divisions and cell enlargement. He found the conspicuous presence of elongated and isodiametric cells in either transverse or longitudinal sections of the endocarp especially in mature specimens, and this variable development is due to anticlinal and periclinal divisions of the cells. As the endocarp develops, the palisaded condition of cells at the sides towards the loculi disappear and persist only at the apical and basal regions. Some of these palisaded cells in the micropylar region, according to him, divide producing two or three layers of cells assuming an oblique, a horizontal or a vertical position (Fig. ***32*** : *9*).

The process of cell lignification (Fig. ***32*** : *1-6*) starts at the apical region and ends at the basal region and it is found first in the middle of the endocarp layer and progresses simultaneously inwards and outwards to the mesocarp. At first, the lignified cells of the endocarp are colourless, but later turn yellowish brown and finally dark chocolate brown. According to him, the change in colour, like the lignification, proceeds from the stigmatic point to the basal end of the fruit and from the middle towards the sides of the layer of the endocarp.

Winton (1901) has found that the mature stone cells show variability in form, some being rounded, others oblong and still others elongated (Fig. ***32*** : *10*). They are observed by him to be dark yellow under the microscope while the whole layer is dark chocolate when observed with the naked eye. The walls are striated and traversed by simple branching pores and the lumina are very small containing a dark brown substance. The cells near the mesocarp are also observed to have thinner walls and larger lumina than those near the ovary cavity.

The ' eyes ' according to Juliano (1926) show certain interesting morphological peculiarities. There are three eyes, and when only one embryo is developed, one eye becomes functional and the other two are non-functional. He found on examination of the mature nut, the fertile eye appearing to be a depression (Fig. ***32*** : *5*) which is due to the failure of the endocarp (excepting a single layer of cells) to lignify. The remainder of the covering of the eye, according to him, is composed of spongy parenchymatous tissue which morphologically belongs to the endocarp and the fertile eye which became covered only by a very thin plate of lignified cells formed from the palisaded layer of the endocarp and from the outer integument of the fertile ovule.

The morphology of the two sterile eyes varies from that of the fertile eye. The difference, according to Juliano lies in the fact that, in the formation of the shell of the sterile eyes, tissues other than the outer integument of the fertile ovule and the palisaded layer of the endocarp take an active part.

Tangentially, the fertile eye (Fig. ***32*** : *13*) is a circular structure, at the periphery of which are located vertically and obliquely, tubular cells of the endocarp (Fig. ***32*** : *11* & *12*).

The anatropous ovules at the basal portion of the ovary possess two coats, the outer and the inner integuments (Figs. ***24*** : *4*; ***32*** : *15*). He observed that these two coats in their juvenile stages are composed mostly of isodiametric cells, the peripheral cells of which are elongated and palisaded (Fig. ***32*** : *15*). He found that as the ovules develop, vascular bundles are formed in only the outer integument (Fig. ***32*** : *7*), while the cells of the inner integument remain small and isodiametric.

According to him, only one of the ovules formed in the basal portion of the ovary becomes functional and the other two degenerate. As the fertile ovule develops and its embryo sac enlarges, it fills up one of the three loculi of the ovary and the other two loculi become compressed in the wall of the developing fruit. The outer integument of the fertile ovule and the endocarp wall then come together (Fig. ***32*** : *7* & *14*). The two degenerated ovules, due to the pressure resulting from the growth of the fertile ovule are also compressed, and their cavities are reduced to lunar slits. He found not only the outer integument of the fertile ovule, but also the outer integument of the two degenerated ovules coming in contact with the endocarp.

Juliano observed that the outer integument of the fertile ovule before it comes in contact with the endocarp of the pericarp wall, consists mostly of isodiametric cells, small near the inner integument and increasing in size towards the periphery. The peripheral layer of the outer integument consists of palisaded to squarish cells. The vascular bundles are manifest (Fig. ***32*** : *7*), and the inner integument consists of isodiametric cells of nearly uniform size, bordered by palisaded cells towards the embryo sac.

The outer integumental cells near the endocarp are larger and their walls are very much thicker than either those in the middle of the integument or those towards the inner integument. The lignification of the outer integument, according to him, precedes that of the endocarp and begins at the apical region of the fruit and ends at the basal end and is similar to that of the endocarp. He observed, that as the lignification proceeds to the basal end of the fruit, it progresses from the outer portion inwards to the inner integument and at the fertile eye. The lignification is seen first in the middle of the outer integument and progresses simultaneously inwards and outwards to the endocarp. With the exception of the cells bordering the micropyle of the fertile ovule, which are slightly lignified, lignification of the outer integument is rather homogenous throughout.

Further work on stages of development of the nut, *viz.*, kernel, coconut milk and oil remains still undone and, therefore, deserves the attention of research workers.

The fruit

The fruit of the coconut, botanically known as a fibrous drupe and popularly the ' nut ', consists internally of the endospermous kernel with the embryo embedded in it and externally protected by the fruit coat known as the pericarp which consists of three distinct and well defined regions, *viz.*, the exocarp or epicarp, the mesocarp and the endocarp.

The outermost region of the fruit coat is the exocarp (or epicarp) which consists of a tough smooth and hard fibrous skin which in the ripe fruit assumes green, red, yellow or brown colour. In the young fruit, particularly until the fruit is well developed, it varies in colour depending on the general colouring of the parent tree. It may assume various shades, *viz.*, bright red, pale yellow, pale green, red brown, brown green or dark green. Immediately below this is the fleshy portion known as the mesocarp which in the young fruit is astringent and in rare instances sweet and edible. When the nut develops and matures, this region turns fibrous. The thickness of this region is variable ranging from 2 cm to 15 cm.

Below the fibrous covering is the endocarp which when the fruit matures, develops into the shell. This hard shell in the cross-section of the fruit is more or less triangular in shape and has three ridges on the outside which alternate with the ridges on the fruit. At the basal end of the fruit where it is attached to the fruit stalk, there are three eyes, one on each carpel, normally two of which are quite hard and the third one soft. One side of the triangular cross-section or the carpel of the fruit is narrower than the other two sides. On an examination of the nut, it is found that one of the three segments has a wider angle than the other two. It is in this widest segment that the soft or germinating eye is situated which is easily recognised on the nut as it is bigger than the other two. The fibre over this eye is also softer and generally less compact than elsewhere.

The seed or the kernel or meat of the fruit is well protected by the hard shell and lies immediately below it. Placed between the meat (fleshy endospermous or oily part) and the shell, is the seed coat which is firmly attached to the meat. The meat in the ordinary nut is about 13 mm thick, but occasionally the thickness may go up to 20 mm. In dwarf and ornamental varieties on the other hand, the kernel is generally very much thinner. At the apex of the nut, immediately below the soft eye and embedded in the kernel lies a peg-like body, the germ or embryo, which, on germination, commences to grow and forces its way through the soft eye. Within the kernel is a cavity which in the unripe fruit is completely filled with the liquid popularly known as ' coconut water '. As the fruit ripens, this water gets very much reduced filling the cavity only partially. When stored after harvest, the water is completely absorbed in about five months.

SHEDDING OF " BUTTONS " AND NUTS AND PRODUCTION OF " BARREN NUTS "

The coconut is mainly a cross fertilised crop in which pollination is brought about through the agency of wind and insects. With this seemingly uncertain method of fertilisation, a large number of female flowers in the inflorescence fail to be fertilised. Consequently, many of them do not develop into nuts and are eventually shed. In addition, nature provides a certain amount of safety to prevent exhaustion of the tree from over-bearing, affording the tree to maintain a balance between production and its inherent capacity. It might be for this reason that many of the female flowers or buttons are shed after fertilisation and some of the nuts after setting, fall prematurely and a few others turn barren (Sampson, 1923).

Shedding of buttons and immature nuts

The vexed problem of shedding of buttons and fall of immature nuts, although, known ever since the coconut was cultivated, first attracted the serious attention of research workers in Ceylon (Petch, 1913). Since then it stimulated the interest of workers in other coconut regions of the world and consequently considerable work in this direction had been carried out in Africa, Trinidad, Indo-China, New Guinea, Philippines, British Solomon Islands and India. In these countries, the control of this phenomenon had been fairly well worked out from various aspects of the problem.

The shedding of buttons and nuts in the coconut has been attributed to several widely separated causes, *viz.*, pathological conditions, attack of insect pests, nutritional deficiencies, soil and climatic variations, defects in pollination and fertilisation, structural defects in the flower, abortion of embryos, physiological condition of the tree at the time of shedding, the limited capacity of the tree to bear fruits, etc.

Shedding as a result of fungus attack

In the early days of investigations on this phenomenon, the fall of buttons and immature nuts was regarded to be primarily due to infestation of the flowers with different fungi and insect pests (Dupont, 1924-31, Dwyer, 1937). Most of the early workers, therefore, concentrated their attention to isolate the fungus responsible for the shedding. Investigations by workers in Kenya, (MacDonald, 1924) showed that the falling of buttons and nuts was due to infection of the flowers with the fungus *Colletotrichum* sp., which causes gumming of tissues at the point of their attachment with the inflorescence. In Zanzibar, some workers believed that this was brought about by the gumming disease (Welsford, 1926). In Ceylon (Gadd, 1922, 1923, 1924), the fall of nuts, however, was attributed to the infection of flowers with the fungus *Phytophthora* sp. This view was later supported by research workers in the Philippines (Teodoro, 1925) and India (Sunderaraman and Ramakrishnan, 1924). In Melanesia (Simmonds, 1924) shedding of buttons was seen associated with the infestation of the fungus *Botryodiplodia*. The different species of fungi associated with the shedding of buttons suggest that shedding might perhaps be prevented by timely application of fungicidal sprays. Experiments were accordingly conducted in Ceylon (Gadd, 1923) to determine the efficacy of spraying of Bordeaux mixture as preventive against shedding of immature nuts. The results obtained were, however, not encouraging. The failure in preventing the shedding of buttons with spray of fungicides resulted in the belief that this is perhaps brought about by some cause other than fungal infection.

Shedding resulting from attack of insect pests

A few workers engaged in investigations on this problem believed that the shedding of buttons and nuts is due to the attack by insect pests. This theory was first advanced by workers in the British Solomon Islands (Dwyer, 1937) and Fiji (Taylor, 1930). In Taveuni Islands (Simmonds, 1951) the shedding of nuts was observed to be largely due to the attack of the buttons by a moth, *Acritocera negligens*, a beetle, *Diocalandra taitensis* and rats. In the recent investigations in British Solomon Islands (O'Connor, 1950), it has, however, been observed that the premature nut-fall was caused by a Coreid bug, *Amblypelta cocophaga* which, however, was found to be driven out by some species of ants, *viz.*, *Oecophylla smaragdina subnitida* and *Anoplolepsis longipes*. It was also seen during these investigations that some species of ants *Pheidole megacephala* and *Dridomyrmex nyrmecodia* which cannot themselves suppress the bug *Amblypelta*, tend to drive out the beneficial species of ants. It was, therefore, suggested that to reduce shedding of nuts caused by the bug *Amblypelta*, the trees should be first dusted with insecticide to kill both the ants and the bugs, followed by the introduction of ants (*Oecophylla*). At Pilicode (India), the percentage of buttons shed due to insect attack, disease or rotting was low and negligible in all seasons (*Annual Report*, 1942-47).

Shedding due to nutritional deficiencies

In recent years, nutritional deficiency in the soil has been considered to be another factor responsible for the shedding of buttons. In both the temperate and tropical countries, the application of nitrogenous manures has often been found to increase setting and consequently increase yield. Comparative analysis of various plots in Indo-China (cited by Gadd, 1923) led to the conclusion that the fundamental cause of shedding was the insufficient nourishment of the roots which was remedied by the application of nitrogenous manures. Later observations on this aspect in Ceylon (Gadd, 1923) were, however, contradictory as nut-fall was observed even in plots which were regularly and liberally manured and shedding was comparatively less in other plots which rarely received any manurial treatment. Other workers in Ceylon (*Annual Report*, 1947) found that fertiliser applications increased the total crop by an increased production of female flowers rather than by reduced percentage of shed buttons. According to Patel, when the production of female flowers was high during March, April and May the percentage set was invariably low. Workers in Ceylon (Child, 1950) believed that the fall of nuts was a natural phenomenon since far more female flowers were produced than the palm could bring to maturity. But the observation that the shedding of buttons was equally uniform even in bunches that had very few female flowers and occurred at a definite period in the early development of flowers, however, gave an element of doubt whether shedding could really be a natural phenomenon. Some workers (Child, 1950) believed that shedding of buttons is an outcome of weakness of the bunch stalk and want of mechanical strength in the tissue.

Shedding caused by unfavourable conditions

Results of investigations on this problem in Kenya (MacDonald, 1924), British Solomon Islands (cited by Dwyer, 1937) and New Guinea (Dwyer, 1937) showed sufficient evidence to prove that the shedding of nuts is due to the unfavourable conditions prevailing. The results obtained showed that shedding of buttons occurred not only when there was deficit of moisture but also during the wettest times of the year. According to Patel (1938), the shedding of buttons was very high during August, September and November and slightly lower during other months. In Ceylon (Gadd, 1923) it was seen that water deficiency affected not only the setting of nuts in coconut plantations but also resulted in severe shedding of nuts especially after unusually prolonged period of drought and particularly after the onset of the first rains. Somewhat similar results were obtained in studies undertaken in Kenya (MacDonald, 1924). Recently, workers in Ceylon (Park and Fernando, 1940) on the other hand, found that the shedding of buttons occurred principally during the rains of the north-east monsoon which interfered with the absorption of water and the aeration of the plant. Patel on the other hand observed that there was no relationship between shedding and rainfall or drought. He observed that the shedding of buttons was more severe on heavy soils than in others which were lighter. In the Philippines (Teodoro, 1925), it was observed that the disease occurred only in very wet weather and the shedding was far more serious when associated with a fungus. It was, therefore, suggested to increase the spacing between trees when planting to bring about less wet conditions. Investigations carried out at Kasaragod, India (1952) showed that although there was some difference in the percentage of shedding in the different months, the differences were not statistically significant.

Shedding as a result of defective pollination

Imperfect pollination or the lack of pollination as a *prima facie* cause of shedding in the coconuts received fair attention from research workers. Preliminary investigations on this aspect undertaken in Ceylon (Petch, 1913) indicated that it was difficult to determine whether the buttons shed were fertilised or not. This was due to the fact that at the time of shedding, the tissues at the base of the button and along the central canal underwent considerable decay. It was, therefore, suggested that an indirect evidence on this point might be obtained by artificially pollinating all the female flowers of an inflorescence and by bagging another inflorescence and thus preventing pollination to see whether unfertilised flowers fell sooner or later. Unfertilised buttons shed comparatively sooner. Patel observed that artificial pollination did not minimise shedding. In Zanzibar (Welsford, 1926), the fall of buttons was found to be due to the failure of fertilisation caused by the abortion of carpels in the female flowers. Studies on shedding of buttons undertaken at Pilicode (India) (Annual Report, 1942-47) showed that the maximum number of

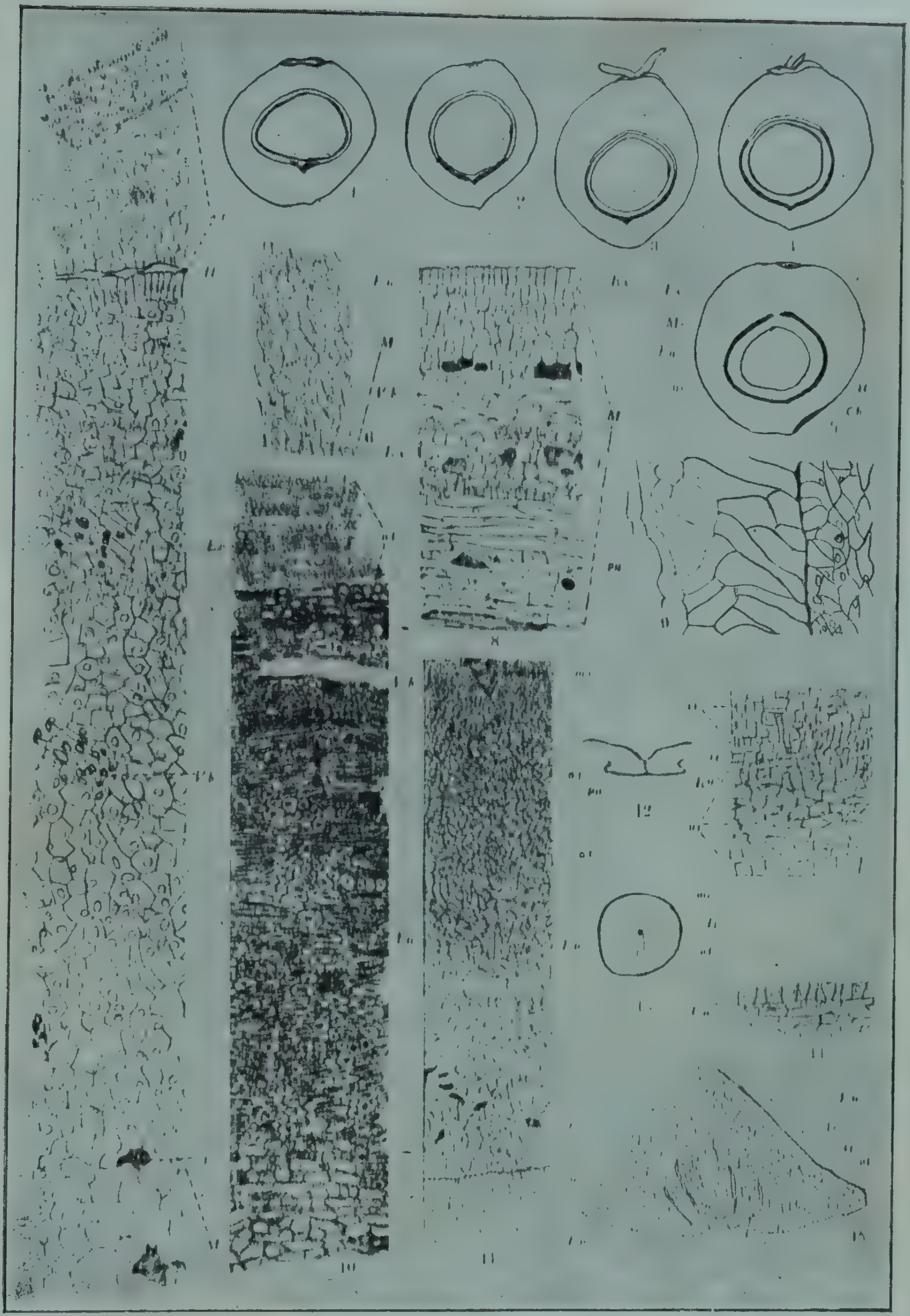


Fig. 32. Development of the fruit — lignification
(After Juliano, 1926)

1 to 5 *Diagrams of the longitudinal sections of the fruits showing the trend of lignification. Basal end* (mi), *stigma* (st), *apical end* (ch), *inner integument* (ii), *outer integument* (oi), *endocarp* (en), *exocarp* (ex) *and mesocarp* (m).

6 *Longitudinal section of the pericarp wall, showing triple differentiation of the pericarp into exocarp* (ex), *mesocarp* (m), *and endocarp* (en).

7 *Portion of the longitudinal section of the side of the ovary and fruit from the embryo sac to mesocarp* (m). *Vascular bundles* (vb) *in the endocarp and outer integument.*

8 *Portion of the pericarp, showing exocarp* (ex) *and mesocarp* (m) *well differentiated.*

9 *Portion of the palisaded cells* (pa) *of the endocarp at the micropylar region of the ovule.*

10 *Diagram of a longitudinal section of the endocarp and portion of the outer integument attached.*

11 *A strip of the tangential section of the eye from the micropyle to the endocarp taken as shown in 12 and 13.*

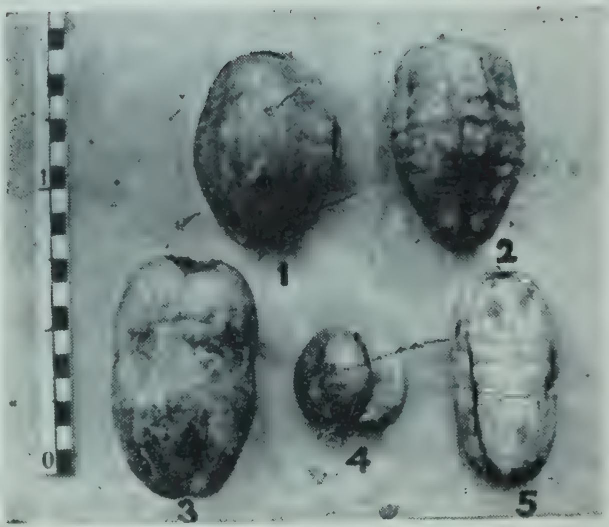
12 *Diagram of a radial section of the fertile eye, showing the inner integument* (ii), *outer integument* (oi), *palisaded cells of the endocarp* (en).

13 *Diagram of a tangential section of the fertile eye taken from the portion indicated in 12 and 14.*

14 *Longitudinal section of a portion of the ovary, showing the integuments of the ovule still away from the endocarp* (en) *and the loculi* (li) *still present.*

15 *Longitudinal section of the anatropous ovule, showing the structure of the integuments.*

Fig. 33. Barren nuts



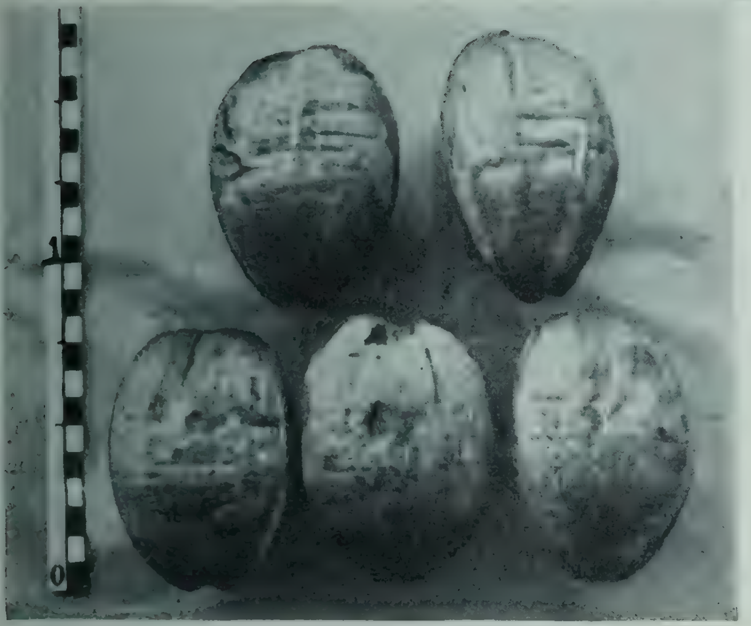


Fig. 34. Normal nuts of the same tree

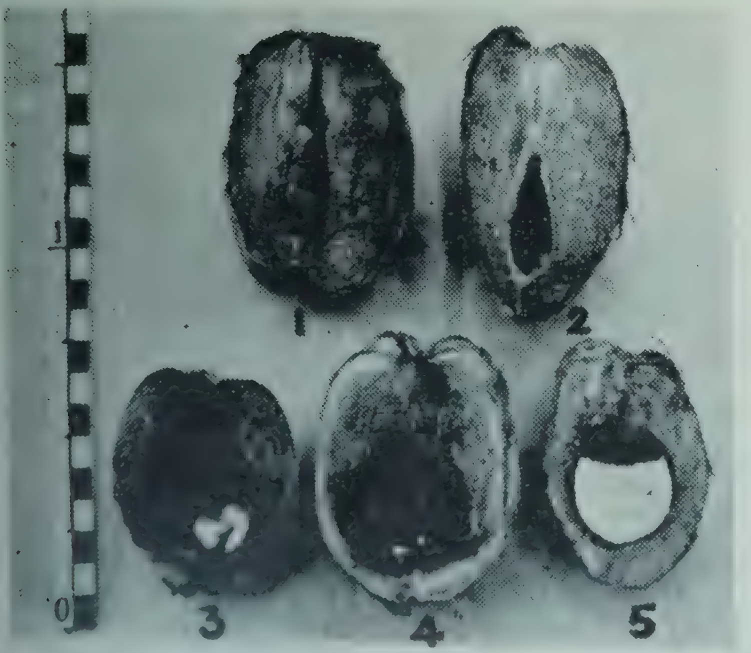


Fig. 35. Types of barren nuts

buttons shed are those in which all the three cells were distinct. This shedding was also attributed to the incapacity of the micropylar canal to enlarge due to insufficient nourishment and lack of sufficient moisture in the tissues of the flower, resulting in the failure of the pollen tube to grow and reach the ovule.

Abscission, a possible cause for shedding of buttons

The water relationship between the fruit and the plant is of importance in the study of the phenomenon of fruit fall. In Ceylon (Gadd, 1923) it was shown how soil moisture was an important factor in the setting of fruits and how conservation of soil moisture could possibly reduce shedding of fruits. As the increase in shedding of buttons followed a period of drought, it was felt that the formation of abscission layer at the place of attachment to the stalk, may perhaps, cause shedding as a result of severe drought. Workers in Ceylon (Gadd, 1923 ; Child, 1950) suggested that as all the attempts at control of shedding of nuts had failed, spraying with hormones might well be tried to check its incidence. Although convincing and conclusive evidence had been gathered on the use of hormone sprays in the control of shedding of fruits in arboreal crops, its applicability to coconuts was not considered for obvious reasons. Coconut being a monocotyledonous crop is devoid of cambium and the occurrence of abscission layer was, therefore, hardly conceivable. Recent successes in grafting of monocotyledenous plants like paddy and sugarcane which were also devoid of cambium, however, proved that in the absence of cambium, in these crops, certain meristematic tissues notably the intercalary meristems could perform the functions of the cambium. These results, however, opened up a new avenue of work in finding out possibilities of utilisation of hormone sprays in the control of shedding of buttons and immature nuts in the coconut.

Failure in the past to find a causative organism associated with this phenomenon often gave rise to the belief that the cause of shedding might be perhaps due to physiological or environmental conditions and this view was supported by workers in Ceylon (Gadd, 1923) and in Trinidad (Briton Jones, 1940). The former explained his view by taking the illustration of the root of the coconut, which when arrested in growth due to dry or water-logged condition, brought about physiological drought due to the formation of hypodermal thickening up to the root cap reducing the area of absorption of nutrients from the soil. The latter worker showed how the shedding of nuts could be the result of external manifestations and internal physiological redistribution of substances within the plant and, therefore, suggested that the mechanism of growth and development in the coconut be investigated thoroughly before any conclusive results are to be obtained.

Control of shedding of buttons

In coconut, considerable loss in yield had been observed to result from this phenomenon of shedding of buttons. It varied from 55 to 95 per cent depending on conditions prevailing, and on the variety of the coconut. The loss occurring due to this phenomenon on a plantation scale has recently been evaluated by Gangolly (1953), to be about three-fourths of the number of female flowers produced by the tree. The shedding of buttons is reported to be comparatively heavier in the dwarf palms than in the tall ones. Patel (1938) observed higher percentage setting in trees included under the group of heavy and medium bearers than those which are poor bearers. He also found that trees having a good number of female flowers have the lowest setting percentage while this was fairly high in the medium and poor groups. In coconuts, Tammes (1955) observed that most of the buttons were shed during the first two months after fertilisation of flowers. According to Patel (1938) shedding of buttons was at its maximum during the first and second fortnights from the opening of female flowers. Sayeed (1955) observed, that significant shedding occurred from the second to the fourth week after the receptive period. Gangolly (1953) on the other hand found that significantly higher shedding happened during the second and third weeks after opening of the female flowers. Work on spraying of hormones had since been undertaken at Kasaragod (India) and results obtained on these trials have been recorded by Gangolly *et al.* (1956, 1957). Of the several hormones tried, 2, 4-dichloro phenoxy-acetic acid has proved very useful and helped to more than double the setting of buttons and secure increased yield of nuts. The method of spraying the hormone is simple. A hormone solution (60 ppm) to which is added an equal volume of fresh coconut water or cow's urine is applied in a fine spray with a nasal atomiser at weekly intervals for one month on female flowers. The correct stage for commencement of spraying on flowers is after completion of fertilisation, judged from blackening or browning of the apex of the button. After two months, the bunch is judiciously thinned by cutting away the nuts that are observed to lag behind in general development and those that are found crowded in the bunch, thus providing sufficient space for development of the remaining nuts. Small scale trials undertaken with this hormone mixture have shown that on an average 21 nuts yielding 2·745 kg of copra were obtained from the treated bunch as against 7 nuts yielding 0·731 kg of copra in the untreated bunches thus showing a clear net profit.

Premature nut-fall

The fall of immature nuts at a later stage of development of the nut, often causes considerable loss of crop. It occurs particularly when the fruits are almost fully grown but before the kernel or ' meat ' has begun to form. This is largely prevalent in Ceylon, British Solomon Islands, Zanzibar, coastal districts of Kenya and Tanganyika. In British Solomon Islands, the immature nut-fall was so severe on plantations, that little crop was left on the palms. The details of the causes for the occurrence of this phenomenon have been discussed elsewhere. Spraying with BHC and DDT preparations against this malady is reported to have proved very useful in controlling the immature or premature fall of nuts in Zanzibar (Child, 1953).

Production of barren nuts in the coconut

The phenomenon of the occurrence of barren nuts (nuts without or with imperfectly developed kernel) variously known as ' Seedless ', ' Man ', ' Male ', or ' Imperfect ' nuts is a familiar one met with in the coconut. Although this phenomenon is, perhaps, as ancient as the cultivation of the coconut, it had not received, until recently, the attention of research workers to the extent needed. John and Menon (1947) have laid considerable emphasis on the occurrence of barren nuts and made a special plea for the urgent necessity for conducting fundamental studies on it. A detailed examination of the data collected for over 25 years on 1,323 trees in an area of about 30 acres at the Central Coconut Research Station, Kasaragod (India) compiled and presented below, revealed that the occurrence of barren nuts on the plantation accounted for no less than three per cent of the gross annual yield (Gangolly and Nambiar, 1953).

Table 22.—Percentage of barren nuts produced by trees in the plantation of the Central Coconut Research Station, Kasaragod

Blocks	Total No. of trees in the block	Number of trees the data of which were examined	Mean percentage of barrenness
I	184	164	2·44
II	211	192	3·40
III	85	73	5·14
IV	103	95	3·13
V	128	117	2·71
VI	149	139	3·15
VII	157	140	2·39
VIII	158	151	2·46
IX	191	153	2·33
X	113	99	2·71
Total	1,479	1,323	29·91
Mean			2·99

Working on the above basis and considering the average acre production of coconuts, the prevailing wholesale price of the coconut and the estimated acreage under this crop in the Indian Union, they have estimated that an approximate net loss amounting to 105·15 million nuts worth 1·58 million rupees is caused by the phenomenon of barrenness. At the Central Coconut Research Station, Kasaragod this problem has now been taken up for detailed investigations in its different aspects (*Ann. Rep.* 1935, 1948-49). These reveal that in the existing coconut plantations certain trees produce a large number of barren nuts. The barren nuts have certain conspicuous morphological features. They are generally oblong in shape (Fig. *33*) while the normal nuts of the same tree are roundish (Fig. *34*). Although the development of husk in these is generally complete, the quantity produced is very much less as compared with normal ones. The husk in many of these is traversed by longitudinal russets of varying degrees at the place of fusion of carpels resembling a star in a cross section of the nut while in the normal nut this is generally full and invariably bulged out resembling a three-sided nut. Sometimes, the outline of the barren nut assumes an irregular shape. The embryo in the barren nut is mostly absent or when present, it is in varying stages of decay. Often, these nuts are seen with the shell and kernel improperly developed. Fungal infection is also, sometimes, seen infesting the embryo, resulting in the decay of the kernel and loss of water inside. The most common feature of the barren nut is the frequent splitting of the shell during the period of development. The barren nuts met with in the plantations could be tentatively grouped into five distinct types based on certain morphological features.

Type 1

In this type of nuts (Fig. *35* : *4*) the development of husk and shell is normal. The embryo is often absent and when present, is found either improperly developed or in various stages of decay. The development of kernel in these nuts is invariably incomplete, often uneven in thickness. Rare instances are met with where the kernel and water are both completely absent. Sometimes, however, the kernel is absent and the whole cavity is filled with sweet water.

Type 2

In this type (Fig. *35* : *5*) the development of the husk is normal. The development of shell is complete but it is generally found to be cracked at the base. The kernel is partially developed and rarely absent. The water inside is also absent. This formed one of the two common types of barren nuts met with in plantations.

Type 3

This is a type similar to the above and forms one among the two types of barren nuts commonly met with in plantations (Fig. *35* : *3*). The nuts of this type show the cracks at the apical end of the nut.

Type 4

In this type some parts of the nuts are either completely absent or rendered diminutive due to defective development (Fig. *35* : *2*). The development of husk is normal. The shell is very thick, hard, strong and very much reduced forming pigmy-sized nuts. The kernel is either completely absent or when partially developed, presents globular protuberances.

Type 5

In this type (Fig. *35* : *1*) some of the parts are improperly developed or absent. The development of husk is more or less normal. The shell is rudimentary, solid in form and linear in shape.

Setting-in of barrenness

Till about the fourth month, no marked differences are noticeable between a normal and a barren nut. It is possible to identify these nuts with some difficulty from the fourth month of development onwards, when they are observed lagging behind in external development. About the seventh month, the signs of barrenness become more conspicuous. At this stage, these nuts are generally identified from the normal ones by their peculiar colour, irregular shape and their reduced size and lighter weight.

This phenomenon had attracted in the past very little attention. Among the few published papers, the earliest is the one by Kupfer (1901) which was followed by another by Bartlet and Belling (1907). While these have considerably widened our knowledge regarding barrenness, they have not, however, helped us in finding out a suitable remedy for preventing its incidence. Several causes for this phenomenon have been advanced by research workers. Furtado (1924) believed this phenomenon to be due to defective fertilisation resulting in seeds destitute of embryo. Preliminary trials undertaken at the Central Coconut Research Station, Kasaragod revealed that barrenness could be induced by keeping female flowers unfertilised indicating thereby that defective fertilisation may be one of the possible causes of barren nut production. Nutritional deficiency in the palm is also considered to be another cause attributed to the incidence of barrenness. There is also a popular belief that application of common salt reduces the production of barren nuts. Preliminary work done in this direction at the Central Coconut Research Station, Kasaragod (*Ann. Rep.* 1947) to determine the possibility of reducing the incidence of barren nuts through heavy manuring with 2·722 kg of ammonium sulphate, 1·814 kg of bone-meal, 27·215 kg of ash and 90·718 kg of green manure per tree, failed to show marked beneficial results.

Increased production in the palm is also believed by some to be yet another possible cause for the production of barren nuts. A small scale trial in this direction was undertaken at the Central Coconut Research Station, Kasaragod (1948-49) to find out how the incidence of barren nuts could be checked by submitting these trees to tapping them for the juice. The results obtained, however, showed that there was no reduction in the percentage of barren nut production.

Trends in Production

Preliminary work undertaken by Gangolly and Nambiar (1953) has shown that production of barren nuts formed an erratic feature in the coconut. A large number of trees (69·72 per cent) in a plantation produce only 1 to 2 per cent. Trees producing barren nuts to a larger extent are relatively rare. While 2·34 per cent of the trees were observed to be completely free from signs of barrenness, 6·12 per cent appeared to show this tendency every year. The rest of the trees produced barren nuts for one or more years at random in a ten year period under observation. Very rare instances are met with where particular trees produce only barren nuts. The production of these is observed to be more in trees yielding an average annual yield of 40 to 60 nuts while it is considerably less in trees yielding more than 70 nuts. This phenomenon appears to fluctuate from year to year and is also observed to be relatively high in the months of April to July (*i.e.*, the peak yield period) and low during September-October. Of the different types of barren nuts met with, those with cracking of shell is relatively more common than the other types. Although studies carried out on the phenomenon failed to establish convincing or conclusive reasons for the occurrence of barren nuts, it is not however, improbable that this is caused on account of excessive bearing. This was significant from the observations made in the course of trials on hormone sprays against button shedding. Some of these buttons which were retained on the bunch as a result of hormone spray had a tendency to become barren when the number exceeded a reasonable maximum which could be supported by the bunch.

GERMINATION OF NUT

When the ripe nut comes in contact with water or moisture for sufficiently long it commences to germinate. The embryo commences to grow in two directions. The plumule or the shoot grows towards the soft eye and the other end of the germ develops an absorbent spongy growth known as the *haustorium* or the *apple*.

The haustorium swells and continues to grow till it completely fills the cavity and is in close contact with the endosperm or the kernel (Fig. *36*). Its very finely corrugated surface exposes a very large absorptive surface area. In colour, this apple is pale yellow and in structure it consists of loosely connected thin-walled cells with large interspaces between them. Strands of vascular tissue which branch freely, run through the apple and converge to the soft eye to carry food from the kernel to the young plant. The combined strength of these strands passing through the eye prevents the breaking away of its attachment to the apple. The haustorium initially absorbs food materials from the coconut water and later on from the kernel and supplies it to the young plant. It does this by breaking the kernel into absorbable material with the help of enzymes. The shoot or the plumule meanwhile presses against the soft eye, with the help of the hard horny surface of the topmost scale leaf in the shoot and forces the lid from the soft eye.

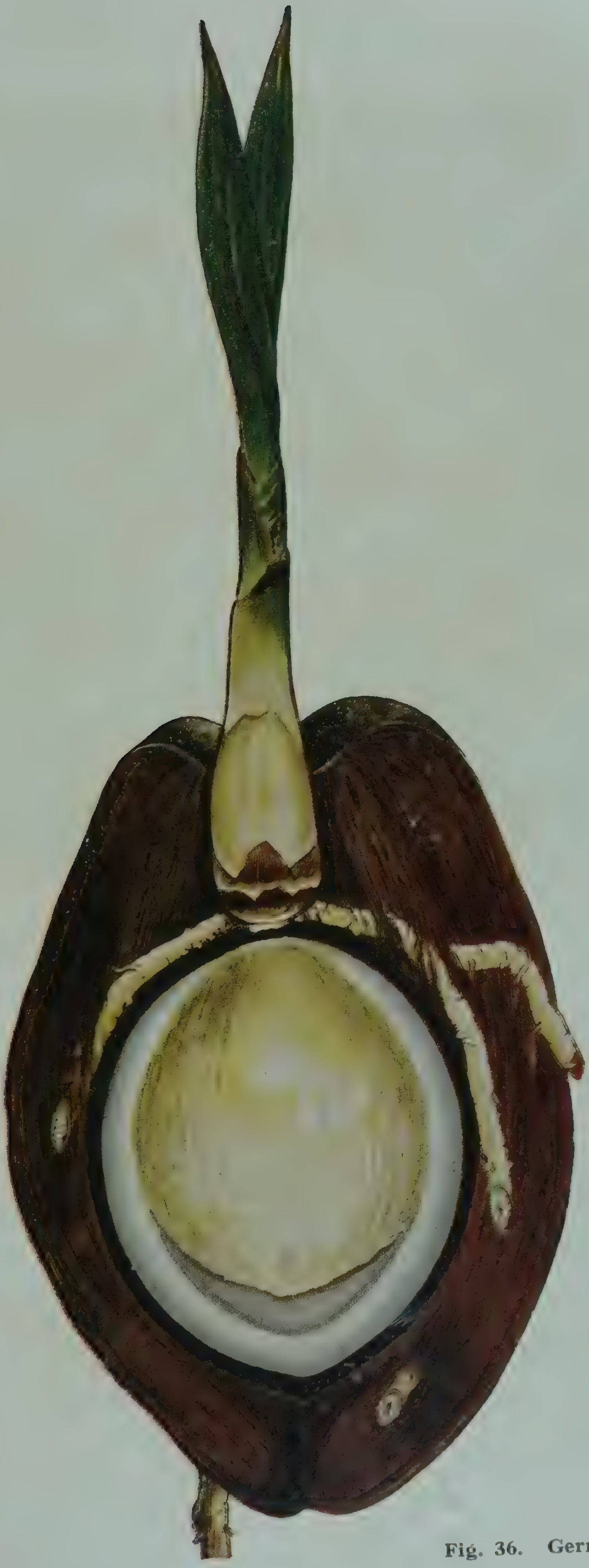


Fig. 36. Germinating seed coconut

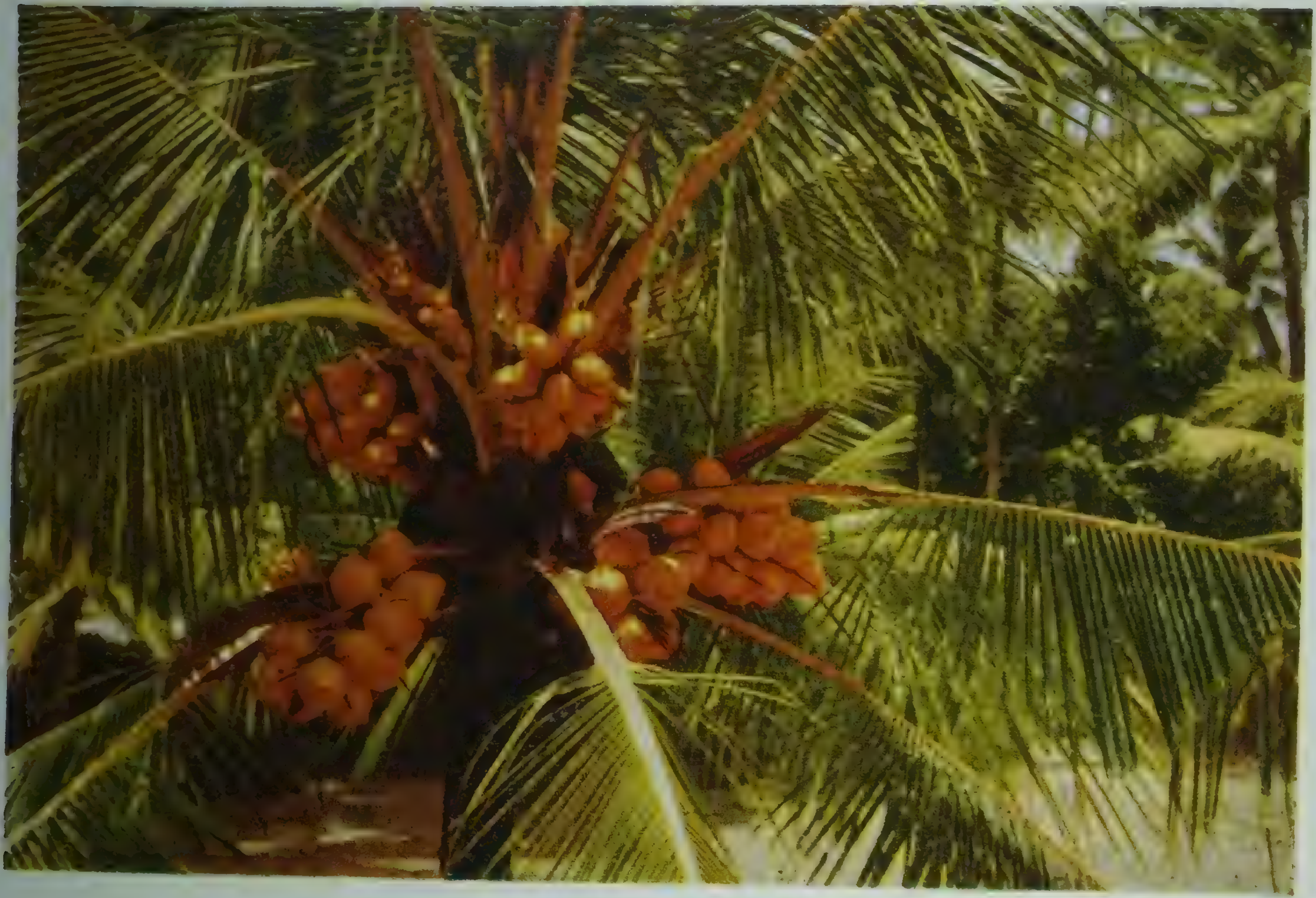


Fig. 37. Dwarf orange

When it emerges out of the soft eye, it commences to develop rapidly as it meets with little resistance from the fibre of the husk in the region of the soft eye. At this stage, the apex of the shoot is still protected and is enclosed in hard horny scale leaves, the uppermost one providing a sharp point with which it pierces its way through the coarser and tougher fruit coat. About six weeks after germination, the growing seedling produces the first root (Fig. 5). When the seedling has formed four to five roots, there is a marked variation in the direction of their growth. In some cases, they emerge through the sides of the seednut, while in others, they emerge from its bottom and reach the soil. As the roots reach the soil, the seedling starts growing rapidly with the help of food material absorbed from it and the shoot soon emerges out of the husk.

After about three to four months of sowing, which in some cases extend to nine months, the shoot commences to form green leaves. The first one formed is very small and is merely the continuation of the end of the scale leaf. The leaves produced later progressively increase in size. The leaves at this stage are entire and form two wings on each side of the mid-rib. The end of the mid-rib terminates into a long fibrous thread. When the seedling has eight to ten leaves, roughly eighteen months after sowing, it will commence to produce leaves which tend to split into leaflets. The tendency to split is first observed at the base of the leaf between the parallel veins. This process continues till the leaves formed are composed entirely of split leaflets.

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CHAPTER IV

VARIETIES

Variety is generally a term designated to denote a single strain or a group of strains which distinctly differ in structural or functional characters from one another or a group of the same species which can be depended upon to reproduce itself true to type. Hunter and Leake (1933) pointed out that the number of varieties in coconut could not be determined because of the difficulties inherent in such determinations due to wide distribution and partly because of the lack of genetical purity due to cross fertilization. The cross-pollination prevailing in the coconut has given rise to a highly variable progeny of palms. Jack (1923) estimated that in the coconut plantations hardly ten per cent of the trees proved true to type.

The promiscuous crossing occurring in the coconut is responsible for giving rise to a large scale multiplication of single genetically heterozygous varieties widely varying from each other or groups of closely related varieties (Darlington and Janaki, 1945). The occurrence of the latter groups has also been indicated by Copeland (1931). According to him, in certain regions particularly in some of the islands isolated from each other certain types suited to the locality with well defined, relatively constant phenotypic characters were found evolved possibly through generations of natural selection. In the Philippines, the absence of the San Ramon type of coconut in the region of the Laguna variety is an instance in point (Mendiola, 1926). Cook (1901) was of the opinion that varieties were doubtless local at first and their differentiation was probably favoured by isolation in accordance with the general tendency among the palms to form series of similar species of limited distribution. These groups occurring in nature and referred to differently by research workers on the coconut, viz., biotypes, ecotypes, strains, types, races, forms or agricultural varieties may, therefore, be considered as synonymous under the existing knowledge of the palm or at least till all these forms are studied in detail and authentic systematic position of each is determined.

Many such varieties have been reported from the different coconut growing countries. Wester (1918) has recorded about thirty-five distinct varieties of the coconut which number, according to him, is remarkably small, considering the antiquity of its cultivation and its wide distribution. Cook (1901) pointed out that in the Malayan region more than fifty sorts were reported with distinct names and characteristics. Omar (1919) recognised fourteen forms or races in Singapore. According to Burkill (1919), there were twenty races recognisable at Kuala Kangsar in Malaya. Simmonds (cited by Copeland, 1931) listed thirty varieties. In Java, Jumelle (cited by Copeland, 1931) stated that at least twenty-five varieties were known. According to Jumelle and Hubert (cited by Copeland, 1931) there were more than forty varieties of coconut in the Philippines. Shortt (1885) named thirty varieties from Travancore. Hooker (1894) mentions *Cocos nucifera* Linn. as the most commonly cultivated species and *Cocos nana* Griffith as a small low variety grown in the Maldivi Islands. Stockdale (1924) cites Rajapakse in Ceylon identifying nineteen distinct types differing from one another in respect of external features, viz., shape and size of nut. The best known varieties of Ceylon, Indo-China and the Islands of the Indian Oceain have been studied by Prudhomme (cited by Copeland, 1931). Types of coconuts in Java, Ceylon and Malabar have been described by Boldingh (1920), Kluyver and Reksohadiprodjo (1923). John and Satyabalan (1955) have described three varieties common in the Laccadive Islands.

Although many of these forms were recorded in coconut literature, Copeland (1931) pointed out that the more conspicuously different varieties for the most part were undoubtedly duplicated in the different coconut growing countries. While considerable attention had been bestowed by research workers in the past on projects relating to various aspects of coconut culture, attempts to study the large number of the forms or races or varieties of the coconut occurring in the different coconut growing countries in the tropics have been comparatively few. This is significant from the fact that very few publications relating to such studies are available. The study of the forms and varieties with a view to systematic classification is of vital importance in coconut improvement work. Coconut being a seed propagated crop, requiring an unusually long period of pre-bearing life, the evolution of promising varieties through breeding became a difficult and time-consuming project. The research workers on coconut were, therefore, obliged to rely on the introduction and study of named varieties for achievement of quicker results in their work on coconut

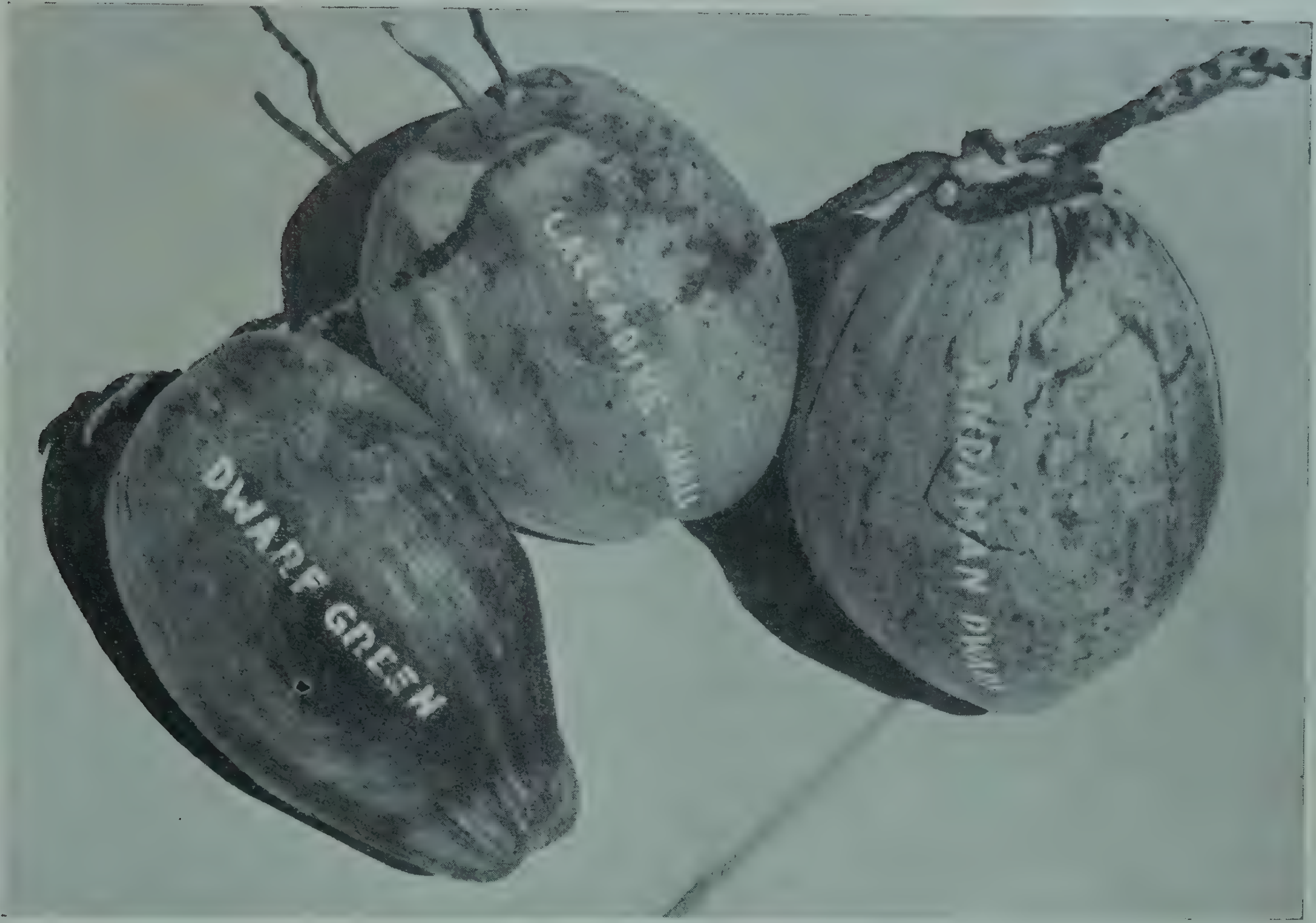

DWARF GREEN

Fig. 38. Dwarf Green, Laccadive small, Andaman dwarf

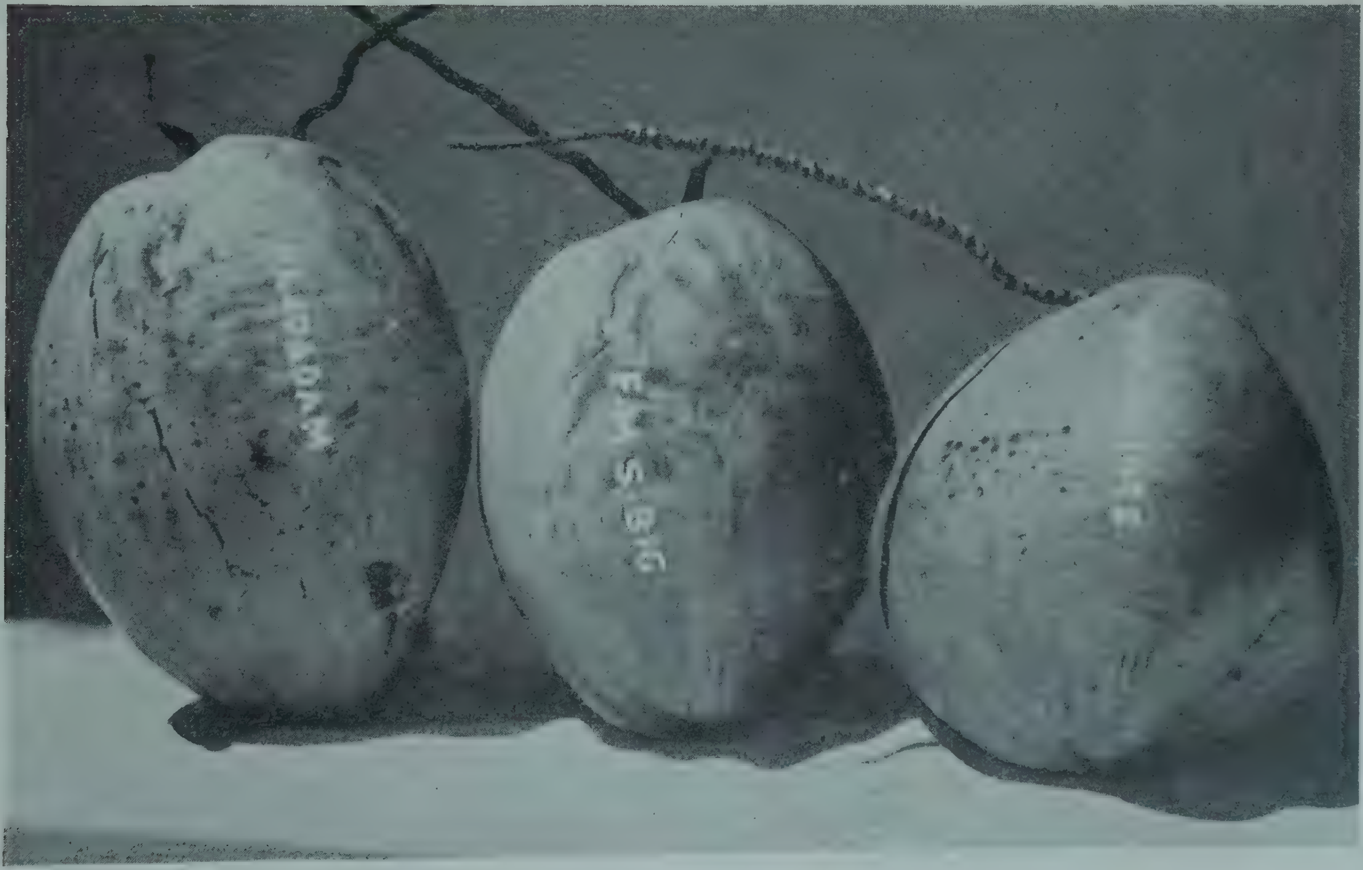


Fig. 39. Kappadam, F.M.S. big and Philippines

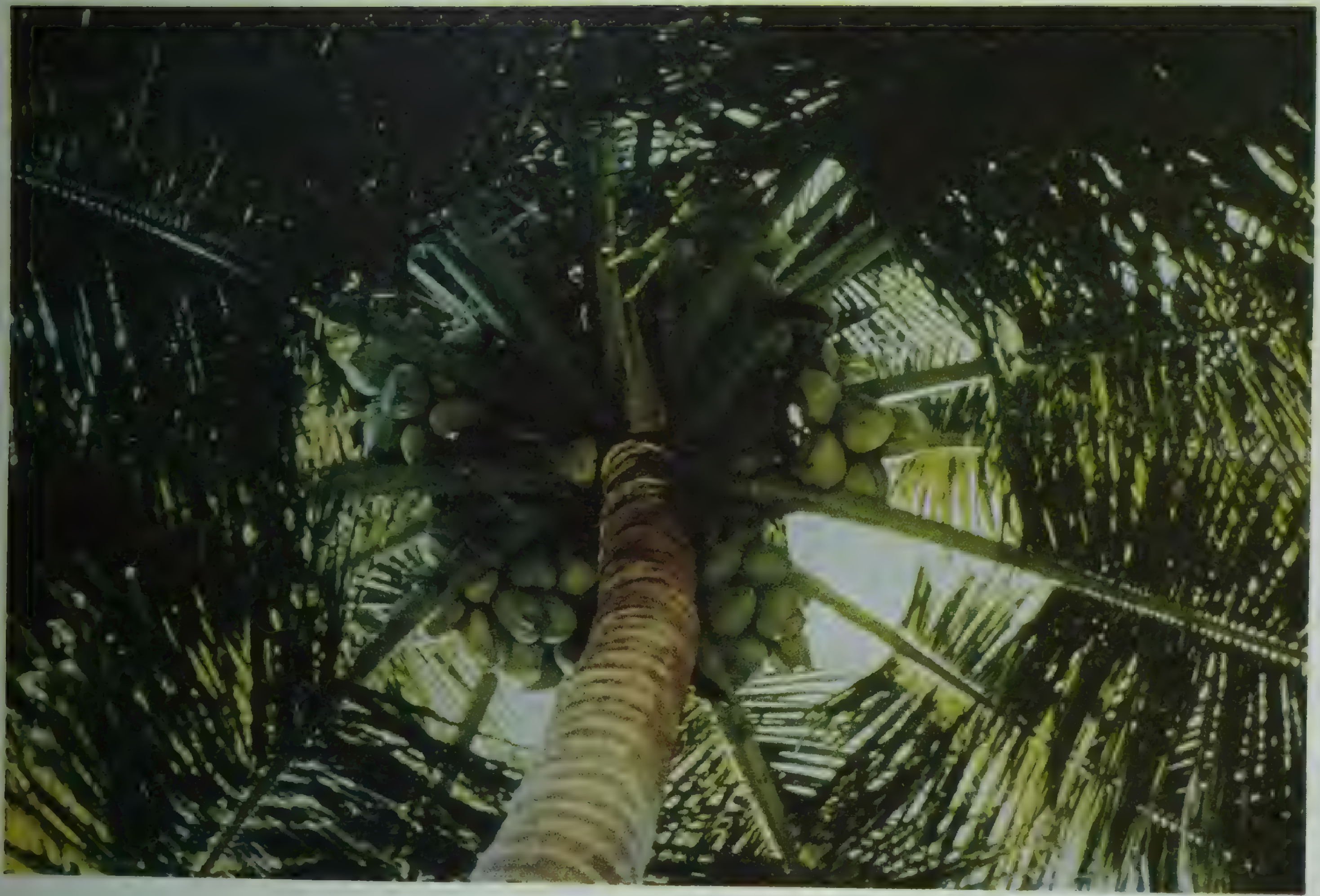


Fig. 40. West Coast Tall

improvement. Although the necessity for such studies was keenly felt, the execution of such a work presented many difficulties. The chaos prevailing in the nomenclature of varieties was a serious handicap in the matter of securing varieties of coconut from different countries.

Among the other contributory factors may be mentioned the highly variable character of the palm, the diversity of forms met with, the lack of comprehensive standardised terminology to describe the different characters of the coconut varieties and above all the absence of a Central or International Organisation to undertake such a project. The work of varietal differentiation as pointed out by Cook in a plant like the coconut is difficult as it may be expected to require much more time than with annual species, probably at least ten times as much, which rendered the problem most unattractive to research workers. Further, the coconut being a monocot incapable of branching and devoid of cambium, the perpetuation of varieties through vegetative methods of propagation does not appear to be practicable.

CHARACTERISTICS OF THE VARIETIES

At the present time most of the growers and research workers on the coconut distinguish almost intuitively the different varieties under cultivation by phenotypic characters alone. In this process they rely largely, if not wholly, on the fruiting rather than vegetative characters. Cook (1901) and Patel (1938) indicated that the coconut varieties differed greatly in size, shape, colour and quality of the nut. Many of these varieties met with in cultivation have been pictured and briefly described or listed in the different publications on coconut. A perusal of these publications revealed that the varieties differed from each other in their morphological characters of the tree to some extent, and to a larger extent in respect of fruit characters.

Cook indicated that coconut palms had some varietal peculiarity. Patel on the other hand, did not observe any major morphological differences between varieties in the studies carried out by him on the West Coast of India. Copeland (1931) observed that the differences in form were unimportant as it is easy in any place with coconuts propagated through the seed to find considerable differences in form. Patel stated that from the shape of the crown, three types of palms could be distinguished, viz., palms having leaves which appeared like the ribs of a fully opened umbrella and so arranged that they receive the maximum amount of light, the palms having leaves orientated at right angles to the stem; and the third type having the leaves which make an acute angle with the stem and generally yielding very poorly.

Some differences have been noted in respect of characters of the leaves. Cook, Copeland and Patel recorded instances of trees, the leaflets of which are united and not split as is the case in the leaves of ordinary trees. Patel also observed that the number of leaves in the palm was positively and significantly correlated to the annual yield of nuts and negatively correlated to the age at first flowering. He pointed out that palms having greater number of leaves could, therefore, come to flower early and yield more.

Some peculiarities in respect of the flowers are met with. Jacob (1941) described a variety which he called *spicata* with unbranched inflorescence and without the usual spikes. He observed in this variety masculinity least expressed, with low number of male flowers (50) as against a mean number of 6,000 met with in ordinary varieties.

Patel reported that planters recognise varieties mainly based on colour, shape and size of nuts. According to him the colour of the nut varied from dark green to deep orange or brick red. Copeland on the other hand indicated that the colour varied from green to yellow and brown. The colour of nuts has been reported to be a somewhat indefinite character (Stockdale, 1924). Shape of the nut is another character which is considered to be an identifiable one. Patel pointed out that some may be globular, while others may be spindle-shaped or even distinctly triangular being nearly twice as long as they are thick. Copeland observed that the differences in shape were usually the characteristics of the tree, the nuts on a single tree being alike and was of the opinion that they could easily be maintained by selection and developed into race characters. According to Cook some varieties appear to have been differentiated for special qualities, viz., flavour of the meat, oil or milk or the abundance and the ease of extraction of fibre. The husk is also sometimes of diagnostic value. In some varieties the husk disclosed a pink colour from which a pink dye could be extracted (Anon., 1884-85). Patel reported a variety, *Kaithathali* which had a soft fleshy edible husk. Alzina (1931) recorded a variety *Caumanis* in which the sweet tender husk is eaten like an artichoke which it resembled much in flavour. Adriano and Manahan (1931) reported a variety *Makapuno* which contained a white, viscous, translucent and jelly-like meat approaching the consistency of hard boiled rice with delectable flavour. Omar (1919) cited a variety *Klapa wangi* which had a fragrant endosperm.

Patel recorded a variety known as *Thairuthengai* where the nuts had no milk but were filled with a jelly-like substance of the consistency of thick curd from which the name is derived. Henry (1920) reported a variety which produced nuts with husk that is easily detachable and very white. Watt (1889) mentioned a small form met with in East Africa which did not possess the fibrous pericarp. Alzina (1931) recorded a variety *Lupisan* which had very little husk but thick and abundant kernel yielding more oil than the others and another known as *Bontanun* where the husk was very thick and spongy and the kernel very thin. He observed certain differences in shells. Shells of certain varieties were always white, others spotted, while still others very black throughout.

On the basis of the growth of the stem and the age of fruiting, coconut palms can be classified into two groups — the ' dwarf ' and the ' tall '. The characteristic features of these groups are described below:

DWARF PALM

As the name indicates, the dwarf coconut is small in stature and commences bearing earlier than the tall variety. Dwarf coconut palms flower as early as the third year after planting and come to regular bearing in the ninth year, *i.e.* in about six years of first bearing. The origin of the dwarf variety has not been determined so far with any degree of accuracy. Handover (1919) and some others (Anon., 1921) suggested that dwarfs were mutants of tall ones, appearing first probably in Java. Jack and Sands (1922) believed the Ivory dwarf coconut to be a mutant from the tall or common form due to some change in genetic factors taking place at rare intervals leading to production of palms with pronounced size differences. These were reported to occur where large coconut areas exist and in widely distributed places. It is generally supposed that the dwarf palms were introduced into Malaya between 1890-1900 by planters from Krion. Other apparently distinct dwarf races are also known in the Philippines, Fiji, Madagascar, Ceylon, Maldives and Nicobar Islands. The dwarf palms are rather limited in their cultivation and the biggest plantation of these in the world is reported to be the one at Singur Nipali Estate on the coast between Fort Dickson and Sepany in Malaya, extending over 500 acres raised from nuts obtained from 12-year-old trees in Krion District.

Handover (1919) invited the attention of coconut growers to the commercial possibilities of cultivation of the dwarf type known as *Nyior Gading* in Malaya which is said to have been imported by the Dutch. Jack and Sands (1922) noted three distinct types of the local *Nyior Gading* dwarf palms based on the colour of the fruit, viz., apricot, green, ivory-yellow with the last type predominating and mixed in plantations of the ordinary tall and semi-tall palms. Jack (1925) pointed out that the natural crossing taking place between the tall and dwarf races gave rise to semi-talls or intermediates occurring as first generation hybrids between the tall and the dwarf. The green varieties of dwarf palms were reported to throw a proportion of semi-tall palms. It was generally assumed in Malaya that dwarfs are self pollinated and are, therefore, genetically pure (with the exception of the green throws). It was reported that the percentage of seeds of dwarf palms breeding true to the colour of the fruit is very high, being as high as 96 per cent in the case of the ivory-yellow variety. It has also been pointed out that the green type should undoubtedly have preference to its less uniform progeny on account of its hardiness and size of nuts. The appearance of families from single mother palms of the dwarf varieties at Port Swettenham in Malaya supported this view as the yield records of these presented a very different picture as the coefficient of variability varied from 36·0 to 41·5, from 14·7 to 74 and 12·1 in that of the yellow, green and red types respectively.

Certain floral characters are associated with these palms. Duration of the male phase varied in these palms between 15 to 24 days with an average of 21 days, while the female phase was eight days. This was shorter than that observed in tall palms in respect of the male phase and longer in respect of the female phase. Inflorescences in the same line in the dwarf variety followed each other after an average interval of four days. In most cases, in these palms, the female phase ended at the time or earlier than the male phase. In a few others, the female phase began before the end of the male phase and the end of the

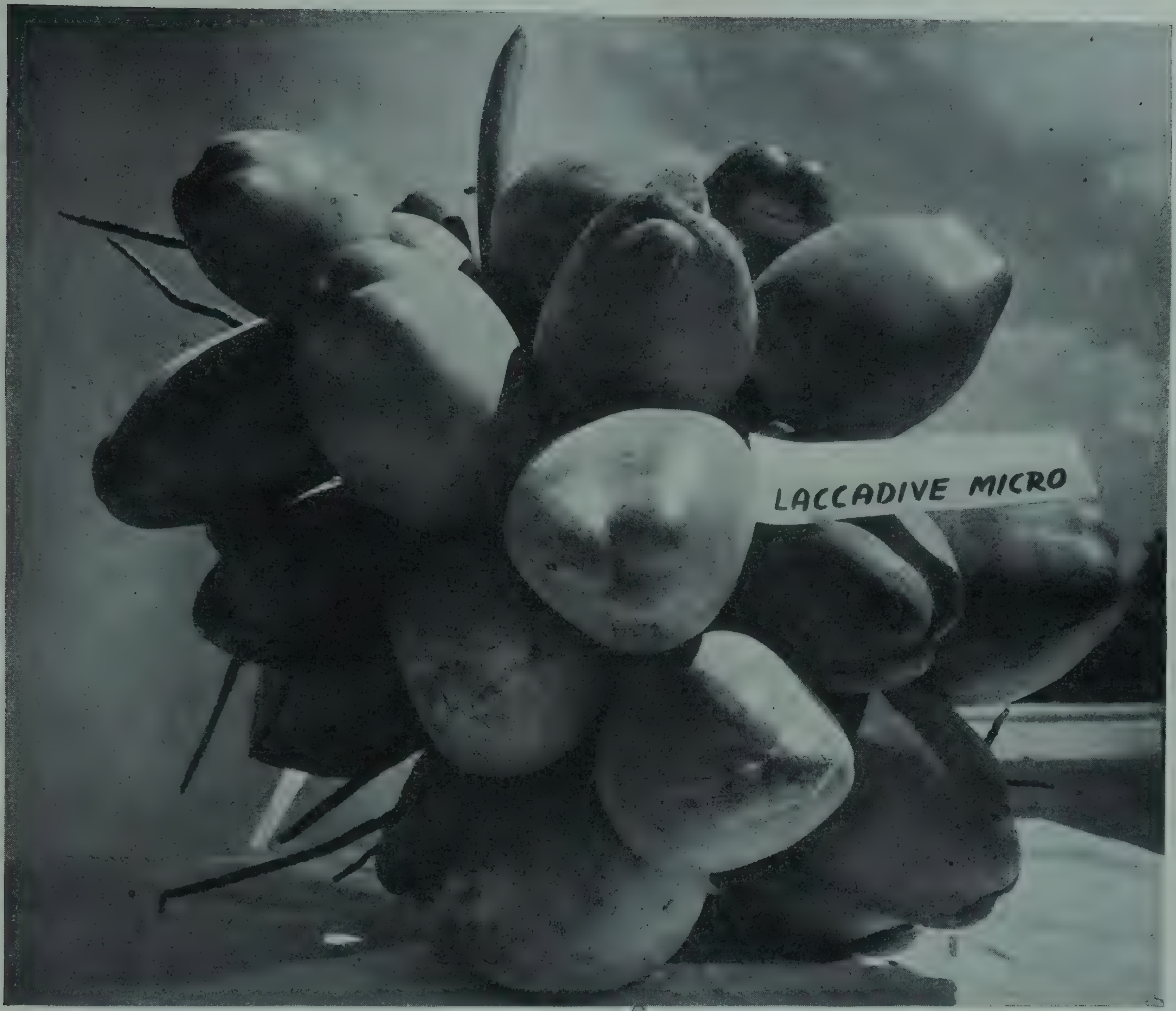
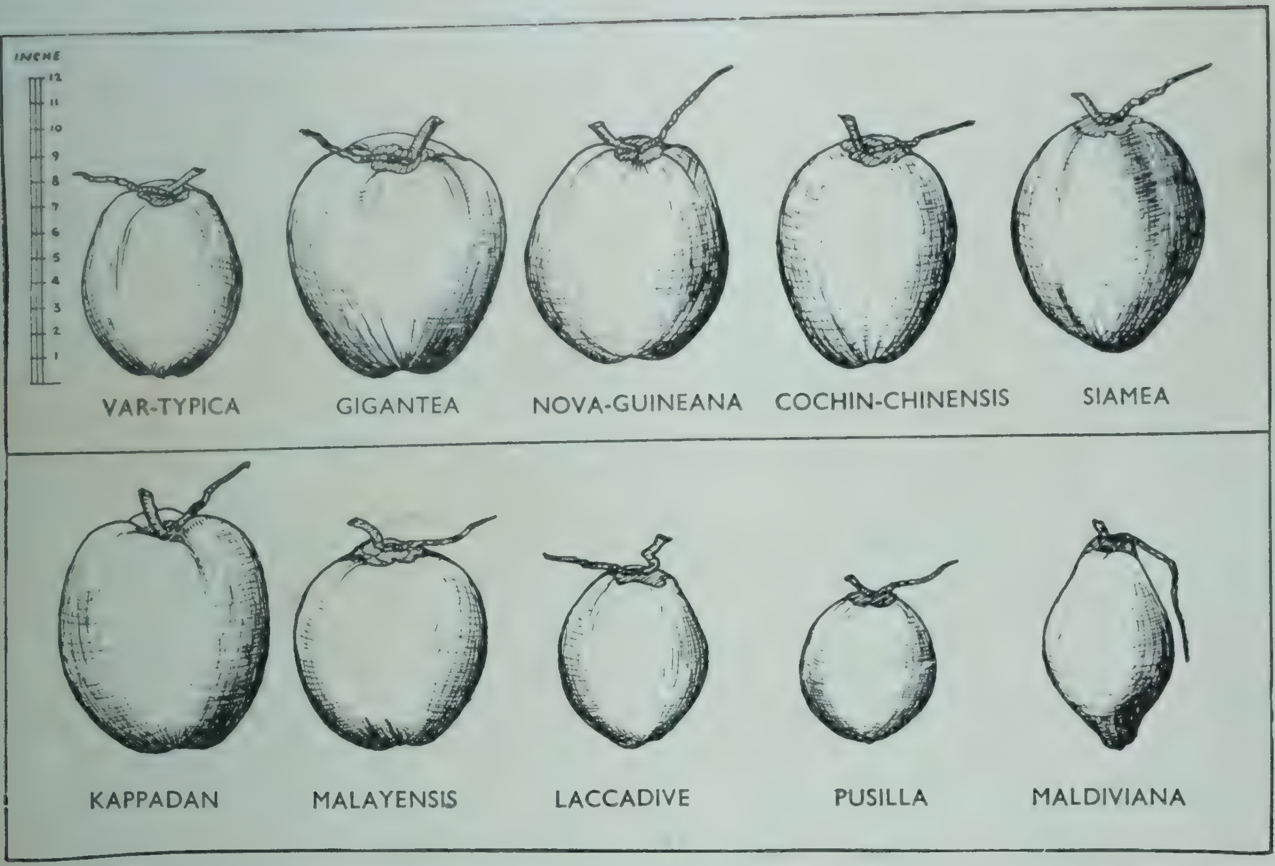

LACCADIVE MICRO

Fig. 41. Laccadive micro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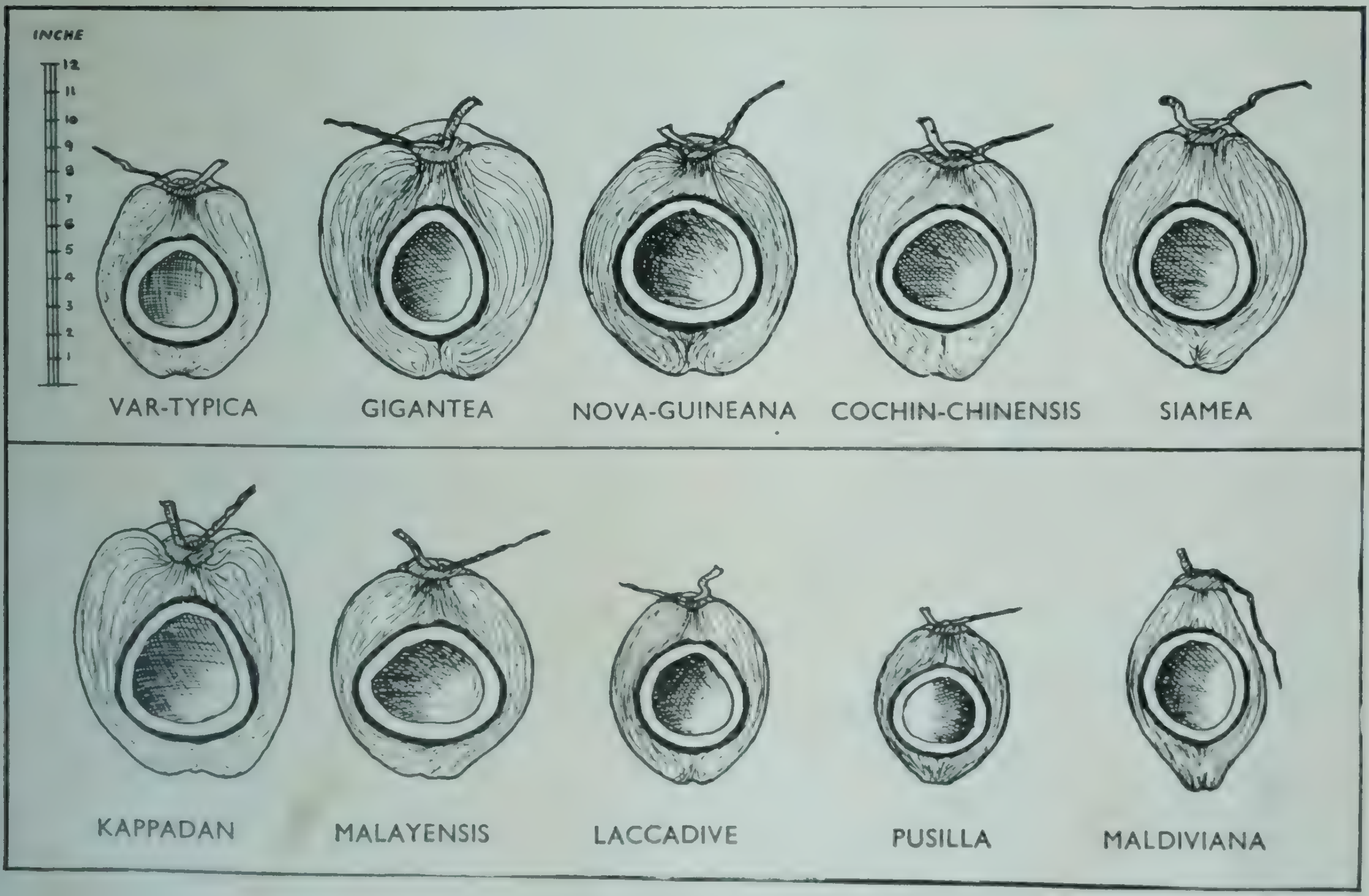
VAR-TYPICA
GIGANTEA
NOVA-GUINEANA
COCHIN-CHINENSIS
SIAMEA
KAPPADAN
MALAYENSIS
LACCADIVE
PUSILLA
MALDIVIANA

Fig. 42. Variety and forms of coconut
(After Narayana and John, 1949)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SIAMEA
KAPPADAN
MALAYENSIS
LACCADIVE
PUSILLA
MALDIVIANA

Fig. 43. Variety and forms of coconut
(After Narayana and John, 1949)

female phase was never more than three days behind the end of the male phase, making self pollination not only possible but very probable particularly high in dry weather, since the pollen grains appeared to maintain their viability for several days under fairly dry conditions.

Although dwarf palms came into bearing early and yielded well, the copra was inclined to be softer, more pliable and leathery and not quite of such good quality as in that from tall palms. Cooke and Jagoe (1938) have shown by experiment that the copra from dwarf palm nuts is of inferior quality to copra prepared from ordinary tall palm nuts. They also reported that it is difficult to prepare hard copra from dwarf coconuts and usually a large proportion of wrinkled, distorted and rubbery copra is produced, as shown below:

Copra	Appearance	Percentage of rubbery pieces	Nuts per picul of copra
Tall variety	Good	0–10	200–284
Green dwarfs	Fair	10–36	350–370
Yellow dwarfs	Poor	18–80	477–667
Red dwarfs	Very poor	50–92	370–513

They were of the opinion that in raising coconut estates, it was advisable to plant only tall palms. In Malaya, the profitable bearing life of the dwarf coconut has been reported to be not so long as that of the tall coconut. Dwyer (1938) reported that larger nuts from the ordinary tall palms are decidedly more valuable than small nuts from dwarf palms. He also observed that where a given number of small and large nuts are compared, the copra can be manufactured more cheaply from the large nuts than from small.

Many varieties of dwarf palms have been reported and described. Hamilton and Grange (1937) recorded seven varieties of dwarf palms in Samoa which were subsequently planted at Buitenzorg, Java. Three varieties of these are reported from the Philippines, two from Fiji and two from Malaya. Rao and Koyamu (1955) have described two dwarf coconut types common in Chowghat area in India.

The description of some of these is given below:

Malaya

1. Klapa Gading (Nyior Gading). It is a distinct variety of the 'medium-dwarf' or 'semi-tall' type common in Malay States, supposed to have been originally introduced from the Dutch Indies. This variety is reported to have first occurred as a mutant in Java. It is a small hardy palm which begins to bear in about three to four years after planting. Bearing is profuse and the annual yield is said to be about 120 nuts per tree. The fruit is ovoid in shape and the apex of the fruit is slightly sunken and the 'eye' small. The kernel is thick and the quality of copra satisfactory. About 8,400 nuts yield a ton of copra which is quite rich in oil. Trees thirty years old, occurring in various parts of Malaya, are said to be bearing profusely. Colour variants with yellow, golden, ivory-yellow, green, brick red, bronze and intermediate colours occur in the variety. The chances for self pollination are greater in this variety than in the ordinary tall variety, 70 to 80 per cent or more of the progeny breed true to type. This is the only dwarf grown on a plantation scale in Malaya (Handover, 1919; Jack and Sands, 1922).

2. Klapa puyoh (Quails coconut). Klapa puyoh is the name given to the green dwarf in Malaya. This has now become much more common than it was before, due to its very early yielding character (Omar, 1919).

Philippines

3. Coco-nino or baby coconut. This is a distinct dwarf form with a short trunk, flowering in about four years after planting. The nut produces thick and hard copra. It is a prolific bearer producing about 100 nuts per tree annually. About 7,000 nuts are required to make a ton of copra. This type is specially valued for tapping purposes (Copeland, 1931).

4. Pugai. This is a dwarf form which commences to bear in about three years after planting. The nut is about 7 cm in diameter with a 2 cm thick husk. These very small nuts are used as curiosities or they may be prepared into candy or stuffed with sweet meats (Copeland, 1931).

5. Lincoranay is characterised by low growth. It includes a number of minor types having fruits red or green and large or small. It includes *Dahili* and *Inano* which possess nuts of smaller size (Copeland, 1931).

6. Pagara
7. Pilipog } These are characterised by thin trunks and short fronds and are delicate in nature (Alzina, 1931).

8. Mangipod. Among the forms intermediate between the *Coco-nino* and the *Pugai*, there is a dwarf nut known in the Laguna region of the Philippines as *Mangipod.* This is also a very early bearer. This variety is said to produce fruit when the tree is so small that the fruit bunch rests directly on the ground (Copeland, 1931).

Fiji Islands

9. N'uleka. The local dwarf coconut of Fiji is called the *N'uleka.* Under ordinary conditions it begins to bear in five years and is a prolific yielder, producing more than 400 medium sized nuts per tree annually (Anon., 1920).

10. N'udam. This type is a very quick and good bearer of round nuts with an exceptionally thin husk and is considered a very hardy type (Anon., 1920).

India

11. Chowghat dwarf. The dwarf types, Chowghat green and orange are delicate and shortlived. They are easily susceptible to diseases and pests. The out-turn of copra is low and the quality is also poor. Chowghat dwarf green maintains high purity, while in dwarf orange both self and cross pollination occur (Rao and Koyamu, 1955).

12. Laccadive and Maldivi dwarf. These are dwarf types of the Laccadive and Maldive Islands. They yield on an average not more than 50 nuts per tree per annum. They give good copra both in quality and in quantity. The copra content per nut is about 115 gm to 145 gm and the percentage of oil in the copra is about 71.

13. Andaman dwarf. This is a dwarf type from the Andaman Islands. It is a poor yielder. The copra content per nut is about 145 gm (5 oz) and the oil content in the copra is about 63 per cent (Fig. *38*).

14. Chennangi. This is a dwarf type from Andhra.

15. Gangabondam. This belongs to the 'medium dwarf' or 'semi-tall' type. The time of first bearing occurs in about four years after planting. The nut matures in eleven months. It is a prolific yielder. The nuts are elongated in shape, medium sized and have fairly thick kernel. They give good quality copra. The copra content per nut is about 230 gm and oil percentage in the copra is about 72.

Ceylon

16. Rath Thembili—King Coconut. Though *Rath thembili* is described under the dwarf varieties of coconuts, it has to be regarded as a semi-tall or medium-dwarf palm. It is largely self pollinated. King coconut appears to be quite distinct from the tall and the dwarf varieties. It resembles the Malayan dwarf. The nut is ovoid in shape (Liyanage, 1957).

Viet Nam

17. Cay dua xiem. This coconut is named the dwarf coconut of Siam. It bears numerous small fruits, poor in copra. Its water is very pleasant to drink. It flowers early at the age of four or five years. The leaves are short (3 m) and the trunk narrow. The Annamites designate it under the name *Xiem lai* (*Xiem metis*). It is a palm with a thick trunk, short with leaves as long as those of tall varieties and bears profusely (Lam-Van-Vang, 1956).

TALL PALM

This is the ordinary or the common tall variety of palms most extensively grown on a plantation scale in all coconut tracts of the world. It is a long lived palm living generally to an age of about 80 to 90 years, although, sometimes older trees are also met with. The palms thrive well under different soil conditions varying from littoral sands to red loams and laterites and also under varying climatic and rainfall conditions. It is observed to grow well up to an altitude of 3,000 ft. above the sea level. It is fairly resistant to diseases and pests. The tree attains a height of about 15 m to 18 m or more. It begins to bear in about 8 to 10 years after planting. The palms of this variety are generally cross-pollinated in nature, although, in summer months there exist chances of self pollination due to the overlapping of spadices. After pollination, the nuts mature in a period of 12 months. The nut is medium to big in size varying in shape from spheroid to linear-oblong and with colours varying from green, yellow and orange to shades of brown. The quality and quantity of copra from nuts of this variety are satisfactory. About 6,000 nuts yield a ton of copra. These are generally the palms recommended for large scale planting as they are superior to the dwarf palms.

Many forms of this variety are recorded in the different coconut growing regions. Some of them are briefly described below:

PHILIPPINES

Copeland (1931) and Alzina (1931) have reported the following:—

1. **San Ramon.** This is a very high yielding type with large nuts nearly twice as large as the ordinary. It requires about 3,270 nuts to produce a ton of copra. This is found in various coconut growing countries, ranging from Ceylon across Malaya and Polynesia. This is perhaps the largest nut ever known on a plantation scale. It starts bearing in about five to six years after planting.

2. **Laguna.** This is the ordinary tall variety and represents the typical coconut of the world. 5,600 nuts are required to produce a metric ton of copra.

3. **Lono or Luno.** The nuts have a soft endosperm and hence are not suited for making copra.

4. **Taban.** This type is known as *Taban* in Pangasinan, *Cayamis* in Northern Mindanao and *Klapa Tebu* in Java. The husk of this variety when tender is sweet so that it may be chewed like sugarcane. Its water is tasteless. When the husk becomes harder it is just like the other varieties.

5. **Tataguden.** The nuts of this type have a thick husk.

6. **Tutupaen.** The nuts are small with very thick shell.

7. **Lupisan.** Produces large nuts with thin husk.

8. **Agta.** This is a type grown in the Nisayan Islands of Leyte. The nuts are so dark green that they appear to be almost black.

9. **Busag.** The fruits are very pale green in colour.

10. **Bulao.** This type has pale brown fruits.

11. **Makapuno.** In *makapuno* nuts, instead of a cavity inside the hard endosperm, there is a light, yet firm tissue filling the entire interior of the nut. Makapuno nuts themselves will not germinate but are likely to be produced on trees along with normal nuts. The Makapuno nut is valued as a delicacy. It resembles the *Thairu thengai* met with in India.

12. **Bontanun.** The nuts have very thick husk. The husk is spongy and the meat very thin.

13. **Carahun or Saloquihan.** Shells of this type are thin.

14. **Dailig.** This is stated to commence flowering from the third year of planting.

15. **Palavan.** The palms in this type grow almost side by side like fingers on a hand, although, they are more widely dispersed over-head. The nuts sprout on the palms themselves before falling to the ground.

INDIA

16. Kappadam. This is allied to the ordinary tall type, but is more robust in all characters particularly in the size of the nut which is one of the largest on record. The shape of the nut is broadly ellipsoid. The yield is rather low being about 60 nuts per palm per year. Quantity of copra is high and copra is thick and hard. This type is met with in parts of South Malabar (India) (Fig. *39*).

17. Andaman Giant. This is a type from the Andaman Islands. The palms are of tall stature, massive proportions and majestic appearance. The nuts are green and large, perhaps one of the largest on record. The yield is poor. Though the content is high, the copra is thin and of poor quality. It comes to bearing in about eight years after planting. The palms are resistant to diseases.

18. Andaman. This is a medium type. It resembles the Andaman Giant in all respects, except in stature. It is a good yielder of toddy.

19. Laccadive ordinary. This type resembles the ordinary tall variety. The average yield under ordinary conditions is about 127 nuts per palm per year. The copra content is 155 gm and oil content in the copra is 72 per cent.

20. Laccadive medium. In this type the nut is comparatively smaller in size than *Laccadive ordinary*. The average yield is about 182 nuts per palm per year and the average copra content is about 85 gm to 115 gm with an oil content of 75 per cent.

21. Laccadive micro. Here the nuts are very small compared to those of the above mentioned types. The yield is about 160 nuts per tree per year. The average copra content is about 80 gm to 95 gm per nut with an oil content of 75 per cent (Fig. *41*).

22. Thairu thengai. There are certain palms among the tall type of the West Coast, which are locally known as *Thairu thengai* (curd coconut). In the nut there is no milk but it is completely filled with a jelly of the consistency of thick curd from which the name is derived. The kernel is not hard to make copra but it is good for eating. These nuts do not germinate but a few in every bunch produced by such trees are quite normal and when planted may give rise to trees of this type.

23. Kaithathali. Among the tall palms of the West Coast there is a variety called *Kaithathali* which is rare. It has a soft fleshy husk. In the tender nut, the fibres are so poorly developed that the husk is sometimes eaten raw and is said to be a very good antidote against sea-sickness.

24. Spikeless. This variety is quite distinct from the ordinary coconut palm in having no branches or spikes in the inflorescence. In this variety, femaleness is most and maleness least expressed, because the number of male flowers is as low as 50. The setting percentage is very low. The mature nut is smaller than the ordinary variety. It is found that about 50 per cent of the progeny of this variety breed true to type. It is also found to cross freely with other coconut varieties. This variety is found to be useless for tapping. It has been described as a distinct botanical variety, i.e., variety *spicata* (Jacob, 1941).

25. Gangabhavani. This is a distinct type from Andhra. The nuts are big and oblong in shape. This type gives good tender nuts with sweet water. The copra content per nut is about 168 gm.

26. Verri kobbari. This type from Andhra is found to be almost similar to the Laccadive small. The nuts are small, oblong and tapering at both ends. The copra content per nut varies from 85 gm to 115 gm.

27. Rangoon kobbari. This type from Andhra appears similar to the Andaman Giant. The nuts are big and oblong. The copra content per nut is very high varying from 255 gm to 280 gm.

NEW GUINEA

28. New Guinea. The nuts of this type are large, spherical or ellipsoid in shape, the colour varying from green to brown. The nuts contain plenty of sweet water in the tender stage. The quality of copra is not as good as that of the West Coast tall type. Under ordinary conditions, the palms yield on an average about 65 nuts per tree per year. It has a copra content of 228 gm and an oil content of 66 per cent (John, 1952).

COCHIN-CHINA

29. Cochin-China. The nuts are large-sized, spheroid in shape and coloured from green to different shades of brown. The water in the tender nut stage is sweet and plentiful. A tree bears about 90 nuts per year. The copra is of fair quality and weighs about 228 gm per nut and has an oil content of 66 per cent.

INDONESIA

30. Java. This is a tall variety with fairly stout trunk. The nuts are medium to large in size and somewhat elongated in shape. It yields about 95 nuts per tree per year. The copra is of good quality. It has a copra content of 200 gm and an oil content of 66 per cent.

31. Takome coconut. This is a variety from the island of Ternate. The tree bears a large number of comparatively small nuts which results from the fact that there is no button shedding in this variety. Many trees of the progeny are found to inherit this character (Tammes, 1955).

SIAM

32. Siam. The nuts of this type are green in colour and medium to large in size and ellipsoid in shape. The palm yields about 50 nuts per tree per year. The copra is of good quality and weighs about 228 gm per nut and has an oil content of 72 per cent.

CEYLON

In Ceylon, the ordinary tall variety is grown on a plantation scale. It resembles the West Coast tall variety of India. It is classified mainly according to the colour and nature of the husk.

33. Rath Thembili. It is known as the "King Coconut" in Ceylon. It is usually described under the dwarf variety (Narayana & John, 1949). It resembles the Malayan dwarf known as *Puyoh*. The nut is ovoid in shape and narrower. It is slightly longer than that of *Nyior gading*. The meat is firm but thinner. "Rath Thembili commonly referred to as King Coconut cannot be grouped under the tall variety of palms and is different from the latter in being semi-tall in habit and largely self-pollinated. King Coconuts appear to be a variety quite distinct from the tall and dwarf varieties" (Liyanage, 1957).

34. Gon Thembili. It is ivory yellow in colour.

35. Navasi Thembili. This is another form of "King Coconut" but having sweet husk.

36. Ran Thembili. This is a green nut having pink coloured husk within.

37. Navasi. The husk in this case is sweet.

38. Penipol. The peculiarity of this is that it has very sweet kernel.

39. Dikiri-pol. This resembles the Philippine *makapuno*.

40. Bodiri. Here the bunches bear large numbers of small sized nuts.

41. Pora-pol. Nuts of this have characteristically thick shell.

SEYCHELLES

42. Cocos Seychellois. Most extensively cultivated in Seychelles. There are two types, green and yellow. Early nutfall is the rule with these. The type is classified as tall, with very curved trunk having dark green leaves, with wide pinnules. The fruit is oblong, the diameter/length ratio being 0·59. The seed is of small size and situated right at the bottom of the fruit near the pointed end (Durocher Yvon, 1953).

43. Coco-raisin. This has bunches of small spherical nuts resembling grapes in shape.

AMERICA

44. San blas. It is an extremely prolific yielder in Central America. It is found not suited to the heavy alluvial clays of the West Coast of Malaya (Smith, 1932).

FIJI ISLANDS

45. Fiji. This type from Fiji resembles the ordinary tall type of the West Coast in India. It is a high yielder and produces more than 120 nuts per tree per year. The copra content per nut also is very high about 225 gm and the oil percentage in the copra is about 70.

MALAYA

46. Klapa jantong. Heart coconut
47. Klapa bulat. Round coconut
48. Klapa besar. Big coconut
49. Klapa sepang. Heart coconut

These constitute the commonest types in Singapore. Most of the Singapore copra is made from these races. The nuts of these differ from each other.

50. **Strait Settlements apricot.** This is a semi-tall type from Strait Settlements. It is a poor yielder. The copra content per nut is about 240 gm. It has got the peculiar character of early maturity and germination.

51. **Klapa laga.** This is too small for copra making and is sold at cheap price.

52. **Klapa nipah.**
53. **Klapa hijau.**
} These are rare types giving high yields. The nuts are excellent for making copra.

54. **Klapa dadeh.** Produces little detached granules of endosperm in the milk in about 4 to 5 per cent of the nuts. It is eaten with sugar as a delicacy.

55. **Klapa kuning.** Yellow coconut — has more sugar in the milk than most other coconuts and hence preferred for eating.

56. **Klapa logi.** The nuts of these are eaten in the tender nut stage.

57. **Klapa wangi.** Fragrant coconut. Preferred for making medicines. The 'meat' has a pleasant scent.

58. **Klapa sekol.** The shell of this type is fancied for making cups.

VIET NAM

(As communicated by Lam-Van-Vang, 1956).

59. **Cay dua ta.** The palm has large green nuts.

60. **Cay dua num.** The fruits resemble those of the preceding variety. A small conical protuberance is seen at the junction of the three sides. Prudhomme cites a variety similar to this in Madagascar.

61. **Cay dua li.** The palm has large fruits but more elongated than in *Cay dua ta*. The sides are less marked.

62. **Cay dua dai.** It is called *Bindinh* in Cochin-China while this name is unknown in Annam. The fruits are elongated and the variety is suitable for the production of coir because the fibres are very long.

63. **Cay dua tron.** The nuts are round. The palm is called the coconut palm of Vihn long.

64. **Cay dua bong.** The palm has green fruits very similar to those of the variety *Cay dua ta*. When the fruits are young, the kernel has the pleasant and agreeable taste of salad. It appears to resemble the variety *Navasi* of Ceylon.

65. **Cay dua sap.** The fruits have a very sweet pulp.

66. **Cay dua lua.** This coconut palm has red nuts. Perhaps it would be necessary to distinguish two types, one with bright red nuts and the other with deep red ones. The petioles of the leaves are similarly coloured but more lightly.

67. **Cay dua lua lai.** Gradations of colour from yellowish-green to bronze are seen in the nuts and this type is considered by the Annamites to be a hybrid of red and green coconuts.

68. **Cay dua tanquang.** These coconut palms are less tall than the preceding types. The leaves are yellow, fruits when mature, become yellowish-white, elongated and large. It is not a prolific bearer.

NEW CALEDONIA

(Communicated by Le Chef du Service de l'Agriculture, New Caledonia, 1956).

There are many varieties of the coconut indigenous to the islands. Some of them are curiosities.

69. **Nu mi or Nu main.** Coconut bearing red nut.

70. **Nu Kono Cocotier.** Coconut bearing green nuts.

71. **Nu Kaume Cocotier.** Coconut bearing white nuts.

72. **Nu Je Meka Cocotier.** Nuts with stripes of green and white.

73. Nu wa or Cocos sucre. This is a coconut whose husk is sweet and could be chewed like sugarcane.

74. Nu Kafa. The fruits of this type are elongated but the tree is not very productive. The husk in this case has long fibre used for the manufacture of coir ropes.

75. Nu melo. The water of the nut is very sweet.

76. Nu Kita. Produces small fruits from which the kernel is easily detached. Each inflorescence consists of a large number of small nuts.

77. King coconut. This is an ornamental variety with yellow leaves.

78. Cocotier des wallis. The nuts of this type are twice the size and give three times more copra than the ordinary variety. This is being grown on a large scale in Ouvea.

CLASSIFICATION OF VARIETIES

Based on the study of the varieties made at the Coconut Research Station, Pilicode, Kerala, South India, a systematic classification of coconuts has been made by Narayana and John (1949) (Figs. *42* & *43*). According to them the cosmopolitan species *Cocos nucifera* Linn., can be divided into five varieties. A key for the easy identification of coconut varieties prepared by them is given below:

Key for the identification of coconut varieties and forms

VARIETIES

A. Inflorescence unbranched or rarely with one or two small spikes — variety *spicata.*
A.A. Inflorescence normal and always branched.
B. Tall late bearing palms.
C. With both male and female flowers — variety *typica.*
C.C. With only male flowers — variety *androgena.*
B.B. Dwarf and early bearing palms.
D. Vigorous palms bearing in four years — variety *javanica.*
D.D. Delicate palms bearing in three years — variety *nana.*

FORMS OF VARIETY TYPICA

A. Nuts very small (about 1,000 cc in volume) and very many in a bunch — even 100 or more *pusilla* (Laccadive small).
A.A. Nuts not small.
B. Nuts very large (7,000 cc) majestic palms. Copra content low and quality inferior — *gigantea* (Andaman giant).
B.B. Nuts medium large (6,000 cc or less).
C. Nuts about 6,000 cc, copra superior and quantity high about 10 oz to 12 oz per nut.
D. Yield of nuts per tree per year, about 100, *ramona.*
D.D. Yield of nuts low (about 35 per tree per year) — *kappadam.*
C.C. Nuts about 4,000 cc or less in volume.
E. Trunk robust — 90 to 100 cm in girth.
F. Percentage of oil in copra high (74) — *siamea.*
F.F. Percentage of oil in copra low (66–69).
G. Female flower production (annual) — very high (744) — *nova-guineana.*
G.G. Female flower production (annual) low (220) — *malayensis.*
E.E. Trunk of medium girth (73–83 cm).
H. Copra thin (0·82 cm) and percentage of oil in copra low (66) — *cochin chinensis.*
H.H. Copra thicker (1·2 to 1·3 cm) and percentage of oil high (72) — *laccadive.*

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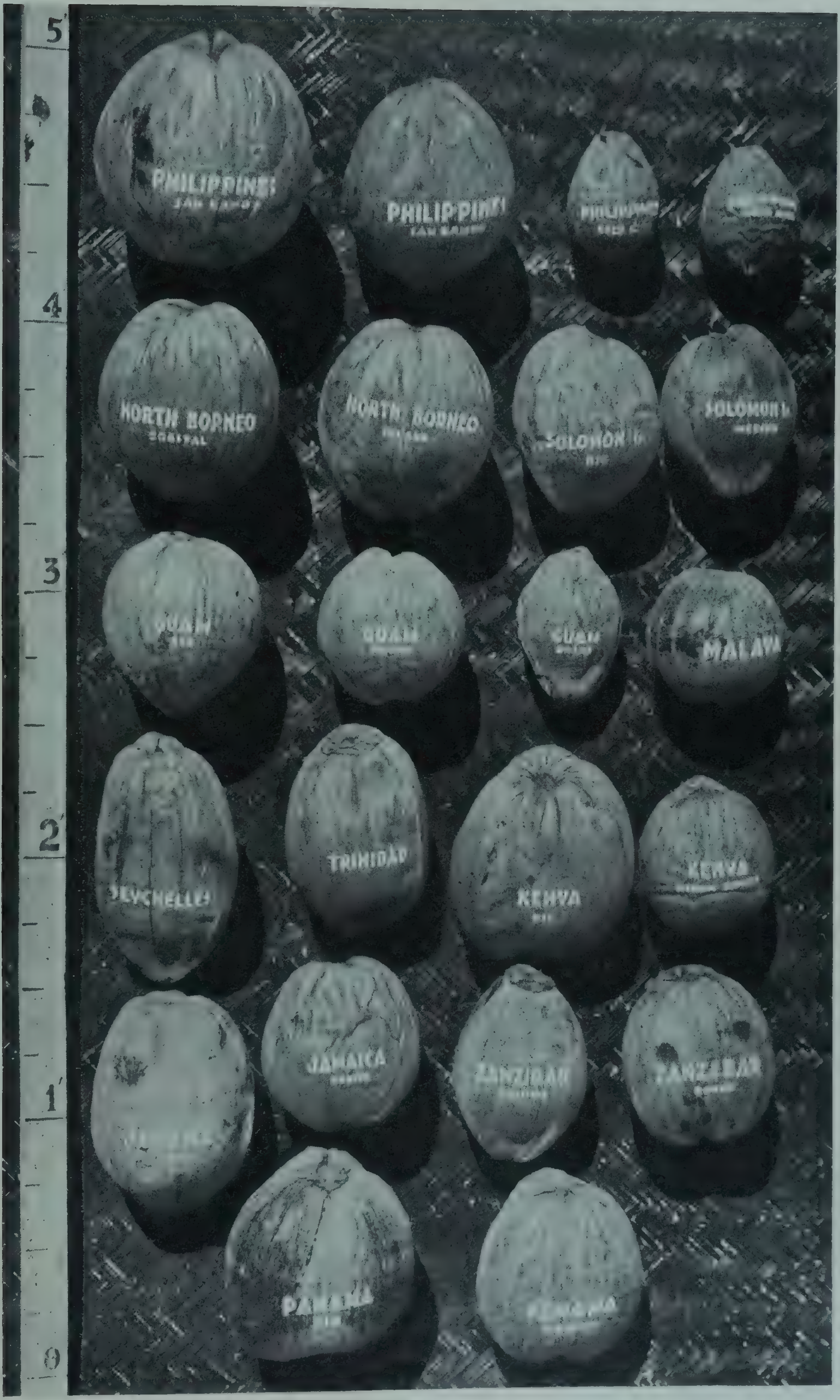
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GUAM
GUAM
MALAYA
SEYCHELLES
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PANAMA

Fig. 43A. Some varieties and forms in coconut.

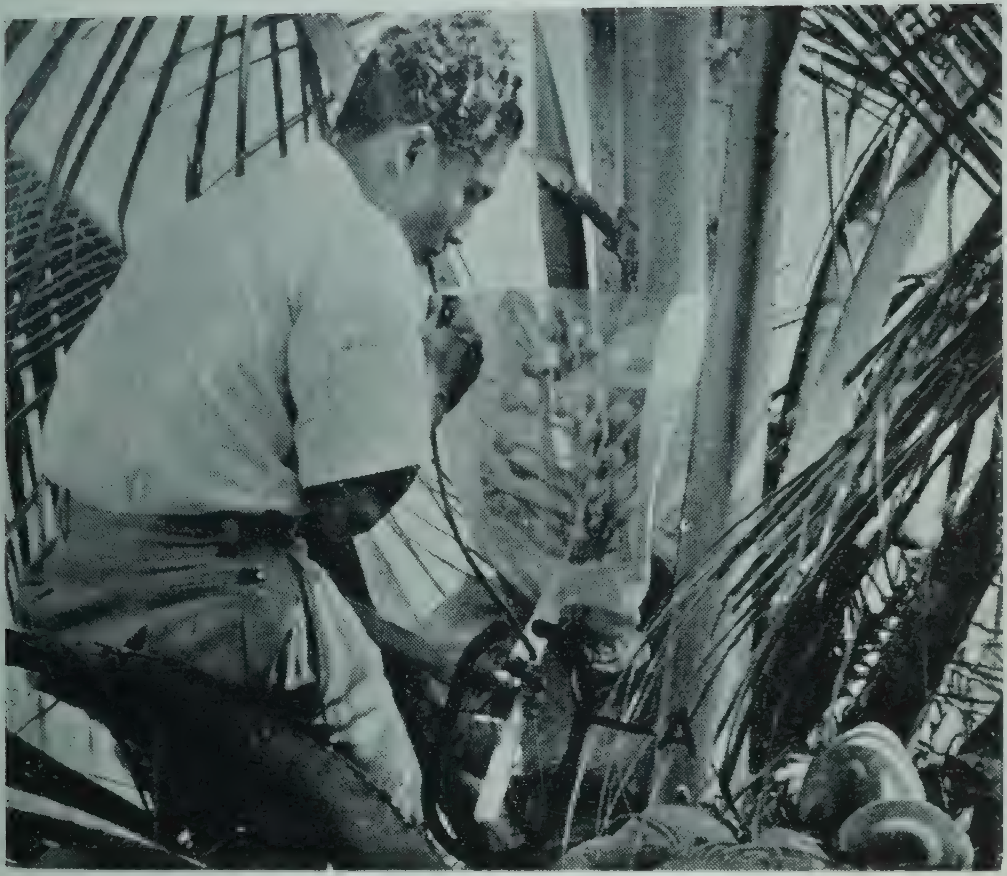

Fig. 44. Pollinator at work
(After Liyanage, 1956)

CHAPTER V

BREEDING

Evolving superior and heavy yielding strains or varieties of coconut by breeding does not appear to have received the attention that it deserves. Dwyer (1938) described some methods for coconut improvement. They consist of: —

1. Introduction of better varieties and strains.
2. Artificial self-pollination and selection in self-fertilised lines.
3. Hybridisation — natural or artificial.
4. Mass selection and strain building.
5. Close and line breeding, etc.
6. Plant-to-row method.

The merits of these methods are discussed hereunder.

Introduction of varieties and strains

The introduction of promising varieties from similar " homoclime " in different parts of the world has been acknowledged from very early times as a profitable method of crop improvement. Various workers have stressed the necessity of exploring this avenue for the improvement of coconuts, viz., Dwyer (1938), John and Menon (1947), Satyabalan (1955), etc. The Governments of some of the countries where coconut is extensively cultivated had adopted the policy of introducing varieties of the coconut from outside, with the object of raising better plantations. Dwyer cites the instance of the German Government in New Guinea introducing superior kinds of coconut, notably *Niu vai* and *Niu iu* from Samoa into the Rabaul Botanic Gardens as early as 1911. The old New Guinea company had introduced selected coconut varieties from outside sources to their plantations in Madang. There is evidence to show that there was frequent interchange of coconut planting material between New Guinea and the Solomon Islands from very early times. Copeland (1931) describes how the colonial Government of Madagascar had collected varieties of the coconut from Ceylon, Indo-China, India, Noumea, Seychelles, etc., for detailed study. Different varieties of coconut from New Guinea, Cochin-China, Java, Siam, Philippines, Fiji, Ceylon, Laccadives, etc., were planted at the Coconut Research Station, Pilicode, by the Madras Agricultural Department. Of these, the introductions from Laccadives, Cochin-China, Java, Siam, etc., appear to be desirable for multiplication under South Indian conditions (Satyabalan, 1955). The former Cochin Department of Agriculture had introduced varieties from Malaya, Sea Island, Philippines, etc., in their experimental farms at Trichur and Vyttila. Recently, varieties from Siam, Philippines, Malaya, Borneo, Solomon Islands, Seychelles, Panama, East Africa, West Indies, Andamans, Laccadives and from different regions in India have been planted at the Central Coconut Research Station, Kasaragod to study their comparative performance under the conditions prevailing in Kerala.

The introduction of even outstanding varieties or forms from distant countries for large scale plantations has to be done with circumspection because many coconut varieties are not cosmopolitan and so they might not perform equally well in another country with different ecological conditions. Smith (1932) cites the instance of the famous " San Blas " coconut of Panama proving to be disappointing when introduced into Malaya. According to Mendiola (1926), in the Philippines, the " San Ramon " type of coconut when planted in Davao, produced nuts which were much smaller than the parent variety. Satyabalan has laid special emphasis on the necessity of studying adaptability and performance of new introductions to particular environment before they are released for large scale planting. This preliminary work would take about 15 to 20 years. It is also necessary that new introductions should be restricted to varieties which are distinct and superior because, Copeland has pointed out, that many of the varieties met with in different lands may turn out to be only duplications of existing ones. In spite of the limitations pointed out above, the introduction of varieties still occupies an important place in coconut improvement.

Self pollination

Harland (1957) has discussed the role of self fertilisation in breeding work on coconuts. According to him, since the coconut palm is a cross fertilised plant, it has almost certainly accumulated by mutation unopposed by selection, a large number of deleterious recessives and these would come to light on selfing. He has indicated that deleterious recessives would also occur in paired crosses, since the parents might be heterozygous for the same recessive gene.

Jack and Sands (1929) were of the opinion that the dwarf variety of coconut showed greater definiteness and generally bred true to type because of the fact that it was commonly self-fertilised. Observations made by Smith (1933) on coconut seedlings from open-pollinated palms, suggested interesting possibilities of self pollination occurring in the coconut. In the dwarf variety, self pollination is the general rule due to the overlapping of the female and male phases in the same inflorescence. Self pollination occurs in certain seasons in the tall variety also (Patel, 1937 ; Dwyer, 1938). Trials in artificial selfing in coconuts were conducted at the Central Coconut Research Station, Kasaragod and these were mainly to study the inheritance of colour (*Ann. Rep.*, 1923-24). For artificial selfing, the pollen is collected from the same inflorescence or from the next one according to availability. Pieris (1929) cited by Cheeseman found that pollen could be stored for about 7 days without deterioration of its viability.

Systematic work on artificial breeding in coconuts was attempted at the Central Coconut Research Station, Kasaragod. From the results obtained on the performance of seedlings from selfed, cross-pollinated and naturally pollinated seednuts, it was observed that selfed progenies were the least vigorous, while seedlings from natural and cross-pollinated nuts were definitely superior in vigour (*Ann. Rep.*, 1942–43). These results are in conformity with the observations made earlier by Patel (1937) who had ruled out the possibility of utilising artificial self-pollination as a method of coconut improvement. Harland, however, indicates that these results cannot be accepted at their face value, as in breeding, depression does not appear to be important in either the dwarf or the Maldivi type. He feels this to be attributable to the fact that different varieties of coconuts will respond to selfing in different ways and to different extent.

Hybridisation

In recent years research workers have emphasised the importance of hybridisation or controlled cross-breeding for coconut improvement, viz., Patel (1937), John and Narayana (1943), Rao and Koyamu (1952), Satyabalan (1956), Liyanage (1956) and Harland (1957).

Harland (1957) has indicated that it is possible by controlled pollination to make hybrids where both the mother and father are known, designated as a ‘ paired cross ’, which formed the basis of a new method of tree breeding as some of the high yielding paired crosses have given a yield more than twice the average ; re-sowing of proved high yielding pairs resulted in a gain of 30 per cent over the unselected commercial material and further cycle of paired crosses between the best of the paired crosses have given still further increase in yield so that with heavy manuring it reached a level about double that of the original unselected type. He, therefore, indicated that long term possibilities of coconut breeding through paired crosses are immense and this fact made it all the more necessary to formulate a sound breeding policy for the future, based on long term possibilities and in conformity with modern genetical ideas.

According to Harland (1957) breeding in coconuts differed from other annuals in that once a pair of trees has been established for crossing to give uniformly high yielding offsprings when crossed, that pair can be subjected to further crossing for the production of seedlings, which, after screening for undesirable seedling characters, can be used for commercial distribution and trial. The elimination rate is at present high and as the paired crossing will give a high percentage of good seedlings the elimination rate is likely to be very low. He also indicated the necessity of determining the pre-potent maternal transmitters which in spite of having been indiscriminately pollinated by miscellaneous males are sufficiently possessed of dominant yield factors to ensure that their offsprings are also high yielding. He also opined that once a maternal transmitter is identified it can continuously be used in paired crosses, self fertilisation and as male parent in extensive crosses with high yielding mother palms. This method, according to him, is the most immediately practical one which can be adopted.

Harland (1957) also observed that the process of identifying male transmitters can be speeded up by the use of dwarf palms as females since they are largely self pollinated and reasonably homogeneous. He has suggested using a number of dwarfs as female parents and pollinating each bunch by different high yielding tall male parent and studying their progeny to identify the most pre-potent males. In studying the progenies he suggested planting 5–10 seedlings from each cross to make a tentative separation.

Although cross breeding offers considerable scope for improvement of the coconut, not much work appears to have been done in this direction. The age to which the coconuts grow, its great height, the long interval between generations, the absence of genetical purity in the material available for hybridisation, the long period of experimentation necessary before a cross-progeny could be declared superior were probably the factors which had been responsible for this. Despite the difficulties mentioned above, some work on hybridisation has been undertaken in some of the leading coconut growing countries of the world like Malaya, India, Ceylon, etc., and many types of intra-specific hybrids are described in coconut literature. The following combinations have been attempted in cross-breeding coconuts.

A. *Dwarf × Dwarf.*

B. *Tall × Dwarf.*

  (*a*) Tall ♀ × Dwarf ♂

  (*b*) Dwarf ♀ × Tall ♂

C. *Tall × Tall.*

A. *Dwarf ♀ × Dwarf ♂.*

Marechal (1928) recorded an instance of crossing the Malayan dwarf with *N'uleka* an indigenous dwarf from the Fiji Islands which formed a distinct group with inflorescences differing in many respects from the Malayan dwarf. He observed that in the hybrids, *N'uleka* characters predominated but there was considerable variation. Some progenies of these hybrids were observed to be high yielding (Surridge, 1932; B.E.V.P., 1953).

B. *Tall × Dwarf hybrids*

Tammes (1955) indicated that crosses between the ordinary tall and the dwarf varieties occurred in nature. According to John and Narayana (1943), Tammes (1955) and Liyanage (1956), crosses between the ordinary *tall* and *dwarf* occurred in nature which showed hybrid vigour and proved superior whether the dwarf parent was male or female. The inclusion of the dwarf element in hybridisation was found to have hastened the early exhibition of the character of early splitting of leaves in the hybrids.

Tammes recorded that the general characters of these hybrids included early fertility with the production of nuts of intermediate size.

(*a*) *Tall ♀ × Dwarf ♂ hybrids*

The earliest work in artificially crossing tall ♀ with dwarf ♂ was done in India in 1932. Patel (1937) made a detailed study of the hybrid progenies and came to the conclusion that hybrid vigour is met with in coconuts. The maximum vigour was noticed when the tall variety was used as the female and the dwarf as the male parent. Hybridisation between selected palms of the tall and dwarf varieties of coconut is conducted regularly at the Coconut Research Stations on the West Coast of India. Rao and Koyamu (1952) made detailed studies on the measurable characters of seedlings raised with seednuts from the tall female parent, the dwarf male parent and the hybrid tall × dwarf. The results obtained by them are reproduced in the following table: —

Table 24.—Measurable characters of seedlings one year after sowing

Particulars	Tall (A)	Tall × Dwarf (B)	Dwarf (C)	Differences whether statistically significant	Critical difference (P = 0·05)	Conclusion
1. Mean number of days for germination ..	98·1	70·2	55·3	Yes	4·67	A, B, C.
2. Girth at collar in inches	3·6	4·2	3·8	Yes	0·23	B, $\overline{\text{C, A}}$.
3. Height in inches ..	32·9	40·8	38·4	Yes	2·32	B, C, A.
4. Number of functioning leaves	3·8	5·0	5·0	Yes	0·33	$\overline{\text{B, C}}$, A.

Earlier, John and Narayana (1943) had also observed hybrid vigour in the progenies of the tall × dwarf crosses. In addition to hybrid vigour, the F_1 progeny had the early flowering nature of the dwarf. The rate of production of leaves and the rate of growth of the stem was greater in these progenies. Liyanage (1956) has also recorded similar observations. He found that in the F_1 hybrid progenies, the mean age of first flowering was 48·6 months from the date of sprouting of seednuts, while the dwarf and the tall took 38·0 and 74·3 months respectively for their initial flowering. Within the first four years, 88 per cent of the dwarf palms and 61 per cent of the hybrids were in flower as against none in the tall variety. He noticed that due to the extra vigour of the F_1 progenies, inflorescences were produced at shorter intervals affording greater chances for self-pollination due to overlapping of the female phase of the older opened inflorescences with the male phase of the younger ones. In the hybrid palms he found that flower initiation was regular since no instances occurred of these trees resting for some time after producing ten to twelve inflorescences as commonly seen in the dwarf palms. The initial harvests gathered by him in hybrid palms compared favourably with those of the tall palms with regard to size, weight of nut and quantity and quality of copra. John and Narayana had recorded a higher initial setting percentage in the hybrids resulting in the production of more nuts. The hybrid nuts resembled those of the tall variety in size, thickness of kernel, quality and out-turn of copra. The table given below gives the comparative characters of the male, female and F_1 hybrid progenies.

Table 25.—Characters of progenies of the parents and hybrids

Characters	Selfed progeny of ♀ tall	Selfed progeny of ♂ dwarf	F_1 Hybrid
1. Height of trunk above ground level ..	No trunk formed	0′ 9″	1′ 1″
2. Girth of trunk at base		2′ 1″	2′ 11″
3. No. of leaves in the crown	11	22	27
4. Mean length of leaf	12′ 8″	10′ 10″	13′ 0″
5. No. of leaves produced during 1941	9	14	14
6. Age at first flowering	Not flowered	49 months	50 months
7. No. of female flowers produced in a year		375	433
8. Setting percentage		5·6	11·7
9. Yield of nuts per year		20·0	51·0
10. Copra content per nut		20·7 gm	165·0 gm
11. Quality of copra		Poor	Good
12. Percentage of oil		70	70

Note:—Characters of tall parent tree used for crossing in respect of items 7, 8, 9 and 10 are 236, 34·7, 81·8 and 206·6 gm respectively. Quality of copra was good and percentage of oil was 71.

(b) Dwarf ♀ × Tall ♂ hybrid

Tammes (1955) cited instances of hybrids between dwarf female and tall male parents. According to him the general characters of the hybrids were early fertility with nuts of intermediate size and distinct male and female phases. The first generation (F_1), he observed, was very homogeneous and did not show the undesirable weakness of the dwarf varieties. He pointed out that in the isles of Halmaheira, an estate of dwarfs lost nearly all its pure dwarf type after a year of production. The hybrids, of which there were a great many, proved to be vigorous as the tall coconut and fruited earlier. He, therefore, recommended growing of this hybrid under circumstances where early fruit bearing was of prime importance as in the new settlements. He was of the opinion that these hybrids could be produced on a large scale by regularly eliminating all male flowers from the dwarf varieties standing near the talls. The instance of a garden in North Celebes was given where the second generation of F_2 progenies segregated in all sorts of types varying from pure dwarf to tall coconuts, although the hybrid type predominated. It was, therefore, pointed out that attempts were made to obtain stable forms combining the good properties of the tall and the dwarf coconuts. The work in this direction undertaken at Kasaragod showed that crosses with these parents had shorter height measurements compared with the tall type while the reciprocal crosses were similar to the tall in this respect.

C. *Tall ♀ × Tall ♂ hybrid*

Comprehensive schemes on cross breeding of palms of the tall variety were undertaken at the Central Coconut Research Station, Kasaragod with a view to produce progenies which would yield the maximum amount of copra. Cyclic crosses involving all important economic characters of the ordinary variety (Var. *typica*), viz., high yields of nuts, high production of female flowers, high setting percentage, thick kernel and large sized nuts were done. The results of these trials are dealt with in detail by Patel (1937) who indicated that controlled cross-pollination was likely to give on the aggregate better results than natural cross-pollination. The study of the progenies has also shown that certain parental characters were decidedly better than others. Hybrids of crosses between parents with high female flower production and high setting percentage were found to be early bearers. Progenies of crosses, viz., high yield × thick kernel and large sized nut × high female flower production also appear to be promising.

Mass selection and strain building

In perennial crops like the coconut which are propagated through seed, " Maternal line selection " according to which attention is paid only to the female parent formed the standard practice from very early times. According to Mendiola (1926), immediate improvement of the coconut lay in the direction of seed selection. Jack (1930) also pointed out that in the absence of prolonged scientific breeding on coconut, the method of selection, if carefully performed, should produce good results, but the choice of the parent tree was largely speculative for, although, the character of the female parent could be ascertained, yet because of its unknown male parent, variation in the offspring was likely to occur to some degree. He, however, was of the opinion that although this method of selection was not likely to produce trees true to type, it was the only practical method for the planter to adopt and the results obtained so far have fully justified the adoption of this procedure.

In recent years, several modifications of this system of selection have been suggested as a means of improvement of the coconut. Establishment of isolated nucleus seed plantations with material obtained by controlled pollination between selected male and female parents and situated far away from all possible contamination from foreign pollen as a means of improvement of heterozygous perennial tree crops has been suggested by Liyanage (1955). A beginning has been made in this direction in Ceylon where a nucleus seed-coconut garden of 200 acres is being established near Chilaw in the Ambakkalle Forest reserves. This is surrounded by forest vegetation about 1 km wide all round and will be planted up with selected seedlings derived from hand-pollinated flowers.

This method has been suggested with the assumption that seedlings obtained in this way would be of high yielding capacity. Harland (1957) has, however, cited evidence to disprove this belief. According to him the results obtained at the Coconut Research Institute, Ceylon (*Ann. Report*, 1949) clearly indicated that high yield is not transmitted by a mixed group of offsprings from high yielding mother palms exposed to natural crossing, as selected seedlings from high yielding palms are very little better than those from low yielding ones. According to him, a high yielder owed its high yield to a variety of causes, viz., unusually favourable environment, selection of good vegetative characters in seedling stage which are correlated with good adult performance, hybrid vigour due to favourable combination of genes in the heterozygous or hybrid phase and genetical superiority in the form of dominant yield genes. As the coconut is cross fertilised and consequently the progeny of any given mother is the result of crossing with unknown number of fathers of varying genetical make up, the chances of producing from any given mother a high yielding progeny are thus very low and if the progenies are mixed it is likely that they would show little if any improvement over a mixed lot of seedlings from unselected or even low yielding mothers.

Although this method cannot undoubtedly be claimed to be a perfect method of obtaining suitable planting material, collection of data gathered from this method is likely to be useful to evaluate the merits of this method and results of this experiment will, therefore, be watched with considerable interest.

Another modification in the method of selection has been suggested by Mendiola (1926) and Rao and Koyamu (1952). They stated that hybridisation followed by selection was inexpedient, if not impracticable, since only comparatively few coconut generations are obtainable in a long period of time. Rao and Koyamu suggested the raising of F_2 progenies from the F_1 hybrid progeny of tall × dwarf cross and carrying out selection of seedlings from the F_2 progenies by rejecting or discarding the dwarf segregates judged by their very early germination and other characters such as delicate, thin leaflets, and the tall segregates by their late germination and general low vigour.

Close and line breeding

According to Dwyer (1938), the expression ' close breeding ' was derived from the fact that, as far as possible, the pollen produced by individual palms in one population was meant to fertilise the flowers of other palms belonging to the same population, all of which were derived from nuts harvested from the same individual mother tree. He also indicated that in practice it would be difficult to prevent the intermixing of the pollen of the several members of the population but some precautions are indicated to eliminate this possibility as far as possible.

Dwyer considered that a continuous system of close breeding would permit of the elimination of inferior strains after each generation until finally only the best strains as determined by performance of yield or any other character under observation are perpetuated. Such a process of elimination, according to him, really amounted to ' strain building ' and did not preclude the building up of other improved seed plots from the best strains, at any time, without interfering with the programme of improvement and without loss of vigour in the resultant progeny. According to him, the method offered the quickest means of improvement which can be increased with each generation of further selection.

Dwyer stated that such method of improvement of coconuts had been followed at Kerawat Demonstration Plantation in New Guinea. Under this method, seed-coconuts derived from open-pollinated flowers of selected individual palms are collected and numbered. The seednuts from each individual palm are kept in separate plots in the nursery. The seedlings are selected in the nursery before planting them out. The selected seedlings are planted in distinct and separate plots in the field so that the population derived from each individual palm constitutes separate small square blocks in the field. In Kerawat Demonstration Plantation owing to considerations of space only a dozen seednuts from each mother palm were planted in individual block or plot. For further planting, the nuts from the centre of the best plots were selected. According to Dwyer it should prove possible to remove the inflorescences from the palms on the borders of each individual plot and thus prevent fruiting. He also pointed out that even by observational methods, many inferior populations could be recognised. These could be cut out and eliminated so that any outside crossing which does occur would be with individuals of superior populations. The step next to recognising any superior population is to plant seednuts from these together in separate plots in new areas. He, therefore, recommended that if possible, this second stage should be arranged for yield-testing as well as to give maximum facilities for close pollination. According to him the close-bred plants are sufficiently heterozygous as not to lose vigour after continued selection in the close breeding plots.

Plant-to-row method

' Plant-to-row method ' in the breeding of crops has led to a great improvement in the production of quality seed material in crops open for cross pollination. Dwyer (1938), therefore, advocated this method of improvement of the coconut from a practical point of view as an adjunct to the ' close breeding ' methods of establishment of isolated seed gardens. This, according to him was comparable with the methods employed at Klang Coconut Experimental Station, Malaya and also at Buitenzorg in Java.

In undertaking this method, he has suggested the selection of seed-nuts of progeny derived from palms which appeared to be superior or as indicated by the various criteria used for selection of good palms (dealt with elsewhere) or preferably by previous yield records. Seednuts are sown in nurseries with progeny of single palms in separate lines for comparison in respect of growth and vigour of seedlings. This sowing in rows makes it possible to eliminate rows of seedlings which are inferior in performance. After rejecting such rows, planting materials from the other rows, viz., vigorous seedlings satisfying all the pre-requisites, are selected. These seedlings are planted side by side under optimum conditions, so that the heredity of progeny of individual parents could be judged to some extent from the very early stage of growth onwards.

The practicability of many of the methods suggested by Dwyer remains to be established. The work involved has to be continued for several generations and continuity of work should be ensured for a long period to get at some reliable results.

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CHAPTER VI

CLIMATE AND SOIL

CLIMATE

The coconut palm is not very fastidious or exacting in its climatic requirements. In fact, it is highly adaptable to a variety of environments. But, for ensuring the development of a profitable and prosperous coconut industry, it is necessary that the likes and dislikes of the palm are given due consideration, particularly when establishing plantations in new regions where it was not grown before. The coconut palm derives its characteristics from the fact that it is essentially a tropical plant. In this connection factors such as latitude, altitude, rainfall, temperature, humidity, sunshine, etc., require detailed consideration.

Latitude

The coconut palm occurs widespread in the tropics. The six primary centres of coconut cultivation, viz., Philippines, India, Indonesia, Ceylon, South Sea Islands and Malaya which together account for over 90 per cent of the world's total acreage and production of the crop lie in this zone between 20°N and 20°S latitudes. The palm is being grown even beyond this region, as far as 27°N and 27°S, but not on an extensive or commercial scale or with much success. The extreme south at which the coconut is reported as growing is south Dauphin in Madagascar while the northernmost point is in Assam in the north-east corner of India. In Florida (U.S.A.), situated at about 25°N latitude, attempts at growing the crop on a large scale did not meet with success. In these extreme latitudes the palm is reported to put on good vegetative growth, but not to bear fruits satisfactorily.

Altitude

The limits to altitude upto which coconut can be grown successfully are set by the latitude also. The farther one goes from the equator, the more is the palm confined to lowlands. In India, flourishing coconut plantations are met with in parts of Mysore State situated at elevations of 600 m to 900 m above sea level. In Ceylon, though the major part of the coconut area is confined to within an altitude of 600 m, palms are under cultivation even at an altitude of 750 m. According to Cooke (1936), the altitude of 600 m appears to be the limit for commercial cultivation in the Philippines. At this elevation the palm has poor and stunted growth, takes considerably long period to bear, and yields only a few nuts of small size. Recently, it has been reported that productive coconut plantations have been established at Tabora in Tanganyika (Africa) at an elevation of 1,350 m. The general opinion is that it may be possible to grow the palm at elevations higher than 600 m to 900 m in areas near the equator, where the temperature remains favourable for coconut growth.

Rainfall

Of all the climatic factors affecting the coconut, rainfall and temperature appear to be the more important ones. While temperature conditions may be uniform over comparatively large areas, rainfall will show considerable variation even within short distances. The coconut palm can grow and bear fruits with a well distributed rainfall of 100 cm but for profitable cultivation, 100 cm to 225 cm per annum, evenly distributed throughout the year appear necessary. It can stand even much higher precipitations if the soil is well drained. As the tree stores little moisture and has no tap roots, it is not suited for regions with long and pronounced dry spells during which the water table goes down considerably. On the other hand, a water table that is too high and remains stagnant over long periods is definitely harmful to the palm.

In the Philippine Islands the annual rainfall varies from 100 cm to 250 cm and is reported to be spread so evenly throughout the year that there is no dry spell or drought. This is one of the reasons for the very high yields at Zamboanga in the Philippines which receives only about 100 cm of rainfall annually.

On the West Coast of India wherein lies the major coconut belt, rainfall increases in quantity, from the south to the north ; but its distribution becomes less and less favourable. Thus in Travancore, situated in the south, the annual rainfall is 300 cm or less per annum, but the dry period extends to only two or three months in the year, whereas in the South Kanara District, further north, the annual rainfall is about 350 cm, with the dry or rainless period extending over about five months. This difference in the distribution of rainfall is actually reflected in the general productivity of the crop.

In Ceylon, the annual rainfall varies from as low as 100 cm to as high as 425 cm in the different parts of the Island. In Chilaw District, noted for coconut cultivation, the annual rainfall is only 150 cm to 175 cm, but the distribution is very satisfactory in that, there are few months during which some rainfall is not received. In Puttalam and Batticaloa districts where the rainfall is low in quantity and erratic in distribution giving rise to recurrent droughts, growth and yield of the coconut are not satisfactory.

In Indonesia, the rainfall is high in most parts of the Archipelago. It ranges from 700 cm in the west to 200 cm per annum in the east with a corresponding increase in the duration and severity of the dry season.

In the South Sea Islands which form another important centre of coconut cultivation, rainfall is generally satisfactory both in quantity and distribution to permit good growth of the coconut palm.

In Malaya, the average rainfall varies from 212 cm to 250 cm in the interior to about 250 cm in the coastal areas and it is distributed fairly evenly throughout the year.

Under some very favourable conditions, it may be possible to raise the crop successfully even in areas which may not appear to be quite suitable for the crop because of inadequate rainfall. For example, Tiptur and Arsikere in Mysore receive only an annual rainfall of 50 cm to 62 cm, but still good coconut plantations are met with in these areas. The reason is that the coconut gardens are situated in the depressions of rolling lands or adjacent to tanks where water accumulates during rainy seasons and there is a steady supply of soil moisture to the palms through seepage.

It may be stated in a general way that when the total rainfall falls below 100 cm per annum or where the rainfall distribution is very uneven, the coconut can be grown successfully only under irrigation. In parts of Saurashtra and Kutch (India), receiving only 25 cm to 50 cm of rainfall per annum, good coconut gardens have been raised because of the availability of abundant supply of sweet water for irrigation.

The palm cannot stand prolonged drought and therefore adequate soil moisture should be ensured either through well distributed rainfall, percolation water or irrigation. The adverse effect of drought is very pronounced in the coconut plantations of the dry zones. The extent of devastation that can be caused to coconut plantations by successive droughts in areas where the rainfall even in normal years is low and badly distributed can be gauged from the experience of Puttalam district in Ceylon. As a result of an unusual succession of four exceptionally dry years (1947 to 1950) some 300,000 palms were estimated to have died and another 700,000 very adversely affected. It can thus be seen that where rainfall is meagre and chances of its failure great, coconut should be grown only with great care and circumspection.

Temperature

Temperature is another important weather factor that has great influence on the growth and productivity of the palm. In fact it is temperature that actually determines the limits to latitude and altitude. The palm requires an equable climate, neither very hot nor very cold. The optimum mean annual temperature for best growth and maximum yields is stated to be 27°C with a diurnal variation of 6°C to 7°C. Nowhere is the palm being grown extensively where the range of temperature is considerable.

On the West Coast of India, the monthly mean of the minimum temperature does not fall below 20°C and the monthly mean maximum rarely goes over 32°C. In Malaya also the temperature is more or less uniform. The maximum temperature is reported to be 30°C to 32°C on the coast and 34°C to 35°C inland. The diurnal range of temperature varies from 6°C to 9°C on the coast to 8°C to 11°C in the interior. A temporary steep fall or rise in temperature, which probably happens occasionally in all places, does no harm. The temperature should not, however, remain at these extremes for long periods at a stretch. High temperatures might cause the young developing inflorescences to dry up, and limit production to those months in the year when the temperature remains at a satisfactory level.

Humidity

The coconut palm, in general, likes a climate characterised by warm and humid conditions. On the West Coast of India, the average monthly humidity recorded at 7·30 a.m. (I.S.T.), rarely falls below 70 per cent. According to Copeland (1931), persistence of highly humid conditions right through is not considered good for the palm from two aspects. One is that it reduces transpiration and thereby reduces the uptake of nutrients. The other is that it provides congenial conditions for the rapid spread of the fatal diseases of the palm, viz., ' bud-rot ', etc. Copeland cites the instance of the coconut country immediately around Mount Banahao where coconut cultivation has been made difficult by the persistence of ' bud-rot ' in a severe form under the high humidity conditions prevailing there right through the year. The leaf disease of the coconut palm in Kerala (India) is found to spread rapidly during rainy months when the atmospheric humidity is high. In Sumatra, too high humidity is reported to cause premature decay of fruit.

Sunshine

The palm requires plenty of sunlight and does not grow well under shade or in too cloudy regions. The lean and lanky growth and unproductiveness of palms growing in shade and the way they try to turn away from obstruction to expose the crowns to the sun, afford sufficient evidence of the avidity of the palm for sunlight. Copeland (1931) has established from experimental data that cloudiness arrests the rate of transpiration considerably. A light haze has been computed to reduce transpiration by one-third to one-half and a heavy cloud to one-quarter of what transpires in direct sunlight. Sunlight has also been shown to raise the temperature of the leaf surface and thereby to promote better activity in the tree. The importance of sunlight in the synthesis of organic food materials by the chlorophyll of green plants is too well-known to need special mention here.

Wind

Copeland states that a dry and windy atmosphere conduces to the best growth of the palm provided soil moisture conditions remain at optimum level, but that where the soil is dry, only little wind is desirable. According to him, windiness increases the transpiration rate and helps in the uptake of more nutrients in the soil solution. But regions which are subject to frequent visitation of violent winds do not appear to be quite suitable for growing the palm. Violent storms cause considerable damage to coconut plantations. They not only uproot or break the trees but also twist the crown or break the leaves and destroy a considerable part of the crop. The cyclones that struck the southern districts of Madras (India) in 1952 and again in 1955 have destroyed so many palms that it will take many years before the level of production can be brought back to that of the pre-cyclone period. A cyclone which struck Jamaica in 1944 is reported to have destroyed 40 per cent of the palms there. The remote possibility of a cyclone occurring, however, is no reason why coconut cultivation should not be undertaken if the area is otherwise congenial for the crop.

Nearness to sea

The fact that coconut palm is largely being grown in regions bordering the sea coast has often created a mistaken impression that the palm will not thrive inland. As already referred to, good coconut gardens are to be found in the Mysore plateau about 240 km to 320 km away from the sea. Similarly in Ceylon, flourishing coconut gardens are met with in the Kandy area situated in the interior.

However, nearness to sea has considerable effect on the climate as well as on the soil. The coastal climate is always more humid and less subject to wide fluctuations of temperature and these conditions, are favourable to the palm. In Saurashtra (Bombay, India), the range of temperature is very wide in the interior (5°C. and below, to 43°C. and above) while it is equable in the coastal area, the mean monthly maximum rarely going beyond 35°C. and the mean monthly minimum never falling below 14°C. In the coastal areas, the growth of the coconut is excellent while it is comparatively poor in the interior.

Another favourable feature of coastal areas is that they generally possess better sub-soil water supplies than those in the interior, because they have at the back of them, higher country and the rain which falls there partly sinks into the soil and moves towards the sea bringing with it dissolved nutrients for the palm's nourishment. The ground water near the coasts is also kept in constant movement by the ebb and flow of the tide and this condition is considered well suited for the growth of the palm.

SOIL

Wide adaptability

The coconut, though essentially belonging to the humid regions of the tropics, is a very adaptable palm which can tolerate a wide range of soil conditions. Cooke (1953) has stated that coconut palms are so numerous and luxuriant, so commonplace, so much a part of the landscape, that they are just taken for granted and one needs occasionally be reminded of their vital significance and extreme importance in whichever part of the world they are grown. According to Briton Jones (1940), there are probably more acres under the tall coconut palm in hot climates than any other crop since it is grown particularly on the coastal belts in almost every tropical country. The crop is grown under extreme conditions of soil which vary from sand to the heaviest clays and on elevations which range from lagoon swampland to hilltops and is found to be exceptionally tolerant to its environment. It should, however, be considered a " sea-side palm flourishing in a sea-washed, well-drained coast with constant moving water in the soil and in an atmosphere of saline moisture." John (1952) has described the coconut as essentially a tropical palm thriving well within 23° north and south latitudes and up to an altitude of about 900 m above sea level. Tempany (1954) believes that the palm grows only in tropical climates and does best on light, easily permeable soils with slowly moving subsoil water at a shallow depth. It can, however, grow well on heavier soils provided they are well drained. There are vast areas of coastal land throughout the tropics which have been and could be used for coconut cultivation (Martyn, 1955).

The coconut palm has been found to be growing on all soils irrespective of the parent material from which these soils have originated. Thus it has been found to grow well on white or gravelly sand, alluvial soils, laterite or lateritic soils, peaty or *kari* soils, volcanic and pumice soils and marine and coral soils.

In the following table data on the chemical analysis of typical coconut soils from South India are given.

Table 26.—Analysis of coconut soils of South India

Locality	Name of village	Percentages							$\frac{\mathrm{CaO}}{\mathrm{MgO}}$
		Nitrogen	Total P_2O_5	Available P_2O_5	Total K_2O	Available K_2O	Lime	MgO	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Malabar	Azhikode	0·094	0·170	0·0180	0·410	0·0060	0·064	0·083	0·77
do.	Tellicherry	0·055	0·050	0·0016	0·400	0·0360	0·076	0·120	0·63
do.	Iringal	0·055	0·062	0·0021	0·198	0·0040	0·180	0·140	1·29
do.	Elattur	0·035	0·070	0·0100	0·076	0·0030	0·074	0·058	1·28
do.	Kadikkad	0·011	0·014	0·0035	0·037	0·0020	0·130	Trace	..
do.	Atavanad	0·223	0·240	0·0017	0·230	0·0063	0·180	0·100	1·80
do.	Padayikkara	0·119	0·170	0·0040	0·164	0·0053	0·100	0·320	0·31
do.	Chemancheri	0·044	0·050	0·0036	0·038	0·0021	0·063	Trace	..
do.	Padiriyad	0·140	0·100	0·0016	0·330	0·0056	0·075	0·050	1·50
Tanjore	Muttupet	0·045	0·054	0·0130	0·780	0·0291	0·450	0·620	..
do.	Koradacheri	0·042	0·032	0·0034	0·370	0·0093	0·870	0·610	..
Godavari	Amalapuram	0·039	0·080	0·0110	0·647	0·0120	1·670	1·330	1·26
do.	Razole	0·078	0·091	0·0100	0·577	0·0190	1·540	0·650	2·37

Table 27.—The results of chemical analysis of some South Indian soil samples

Type of soil	Locality	Depth	Moisture content	Loss on ignition	CaO	MgO	P_2O_5	K_2O	Fe_2O_3	N	Available		pH	Mechanical composition			
											P_2O_5	K_2O		Coarse sand	Fine sand	Silt	Clay
			Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent		Per cent	Per cent	Per cent	Per cent
Sandy ..	C.C.R.S., Kayangulam.	0–8″	0·53	1·13	Trace	Trace	0·031	Trace	0·71	0·090	0·004	Trace	5·5				
		8–17″	0·72	1·12	,,	0·075	0·020	,,	0·86	0·007	0·004	,,	5·5				
		17–72″	0·71	1·69	,,	0·101	0·025	,,	0·75	0·066	0·010	,,	6·0				
do. ..	Nangyar-kulangara.	0–12″	..	..	0·093	0·017	0·011	,,	0·56	0·031	..	..	..				
		12–24″	..	..	0·062	0·018	0·005	,,	0·22	0·016	..	..	..				
do. ..	Keerikad	0–12″	..	1·70	Trace	..	Trace	,,	..	0·127	Trace	Trace	7·2	77·00	17·50	0·80	3·50
do. ..	Changankulangara.	0–12″	..	1·20	,,	..	,,	,,	..	0·089	,,	,,	7·0	87·00	7·50	0·30	0·50
do. ..	Vyttila	0–12″	0·40	1·20	0·169	0·090	0·053	,,	0·72	0·038	0·029	,,	6·5				
		12–24″	0·26	0·90	0·072	0·076	0·048	,,	0·49	0·030	0·031	,,	6·9				
		24–36″	0·24	0·53	0·065	0·076	0·052	,,	0·37	0·028	0·034	,,	6·7				
do. ..	Nileshwar-III ..	0–6″	..	0·78	0·050	0·070	0·015	0·042		0·026	0·001	0·0008					
		6–38″	..	0·47	0·040	0·060	0·013	0·044		0·018	0·004	0·0029					
Sandy loam ..	Chirayinkil ..	0–12″	0·92	2·23	0·120	0·009	0·054	Trace	1·85	0·049	0·003	Trace	6·4				
		12–24″	1·12	3·40	0·085	0·014	0·054	,,	2·09	0·042	0·002	,,	6·2				
		24–36″	1·46	3·10	0·064	0·014	0·049	0·050	2·54	0·044	0·002	,,	5·9				
		36–48″	1·54	3·30	0·078	0·014	0·048	0·012	2·85	0·046	0·001	,,	6·0				
do. ..	C.C.R.S., Kasaragod.	0–12″	0·50	..	0·020	..	Trace	0·130	4·00	0·040	Trace	0·004	5·6	75·60	10·52	1·00	12·75
		12–24″	1·30	..	Trace	..	0·030	0·110	4·50	0·030	,,	Trace	4·2	68·20	8·80	2·00	16·00
		24–48″	..	..	,,	..	0·040	0·700	7·12	0·030	,,	,,	4·4	86·75	2·00	3·15	10·90
Reclaimed sandy.	Ochanthuruthy ..	0–16″	1·16	2·45	0·148	0·193	0·108	0·062	1·90	0·065	0·055	,,	6·4				
		16–22″	1·46	2·78	0·101	0·075	0·109	0·083	1·90	0·054	0·055	,,	6·9				
		22–34″	2·50	3·23	0·137	0·059	0·142	0·222	3·20	0·056	0·055	,,	7·2				
		34–58″	2·82	4·78	0·220	0·045	0·156	0·162	3·95	0·090	0·078	,,	5·7				
do. ..	Kumarakom ..	0–12″	..	6·20	0·009	..	0·009	0·004	..	0·047	..	..	5·2				
do. ..	Kumbalam ..	0–12″	..	0·84	0·206	..	0·022	Trace	..	0·042	..	..	5·4				
Red loam ..	Punkulam ..	0–12″	..	4·06	0·249	..	0·016	,,	..	0·057	..	..	5·4				
do. ..	Quilon	0–30″	2·18	2·55	Trace	Trace	0·088	,,	2·12	0·116	0·032	Trace	5·5	66 00	18·50	2 00	13·50
		30–72″	2·46	2·23	,,	0·090	0·063	0·015	2·14	0·069	0·008	,,	4·5	61·00	20 00	2·30	16·00

Table 27.—The results of chemical analysis of some South Indian soil samples—*Contd.*

Type of soil	Locality	Depth	Moisture content	Loss on ignition	CaO	MgO	P_2O_5	K_2O	Fe_2O_3	N	Available		pH	Mechanical composition			
											P_2O_5	K_2O		Coarse sand	Fine sand	Silt	Clay
			Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent		Per cent	Per cent	Per cent	Per cent
Red loam ..	Nagercoil ..	0–8″	0·69	2·02	Trace	Trace	0·066	Trace	1·77	0·086	0·0160	Trace	6·0	71·50	16·50	2·20	8·80
		8–20″	1·31	3·74	,,	,,	0·017	0·015	2·91	0·107	0·0170	,,	6·0	58·00	15·00	4·30	21·50
		20–26″	1·83	4·84	0·055	,,	0·110	0·035	3·25	0·128	0·0250	,,	7·5	33·00	31·00	8·50	27·00
		26–72″	1·81	6·45	0·066	,,	0·151	0·132	4·26	0·147	0·0160	0·0060	7·0	15·50	42·00	9·50	33·00
do. ..	Nileshwar-II ..	Soil		2·81	0·007	0·14	0·037	0·088		0·049	0·0022	0·0011					
		Subsoil		2·75	0·013	0·18	0·038	0·018		0·025	0·0024	0·0008					
do. ..	C.C.R.S., Kasaragod.	0–12″	2·2		Trace		Trace	0·080	2·72	0·03	Trace	Trace	5·6	80·25	7·28	4·50	2·25
		12–24″	5·5		..		0·004	0·070	3·20	0·03	,,	,,	4·2	83·00	6·64	1·00	1·25
		24–48″	..		Trace		0·060	0·030	4·08	0·04	,,	,,	4·2	81·50	3·00	0·30	11·40
Alluvial loam ..	Tiruvella ..	0–12″	4·0	5·50	0·049	..	0·040	Trace	..	0·081	,,	,,	..				
	Veloor ..	0–12″	..	5·52	0·430	..	0·050	,,	..	0·104	..	..	6·2	47·00	32·00	6·90	11·60
	Nedumangad ..	0–12″	..	5·70	Trace	..	Trace	,,	..	0·127	Trace	Trace	7·2				
Laterite ..	Adoor	0–12″	1·50	1·00	0·038	..	,,	,,	7·45	0·038	,,	,,	..				
do. ..	Kanjirapally ..	0–12″	..	12·41	1·722	..	0·182	0·044	..	0·153	..	..	8·0	29·30	13·00	4·80	41·90
do. ..	Nileshwar-I ..	0–6″		5·50	0·025	0·27	0·044	0·110		0·086	0·0018	0·00089	..				
		6–36″		4·43	0·055	0·29	0·034	0·220		0·044	0·0004	0·00078	..				

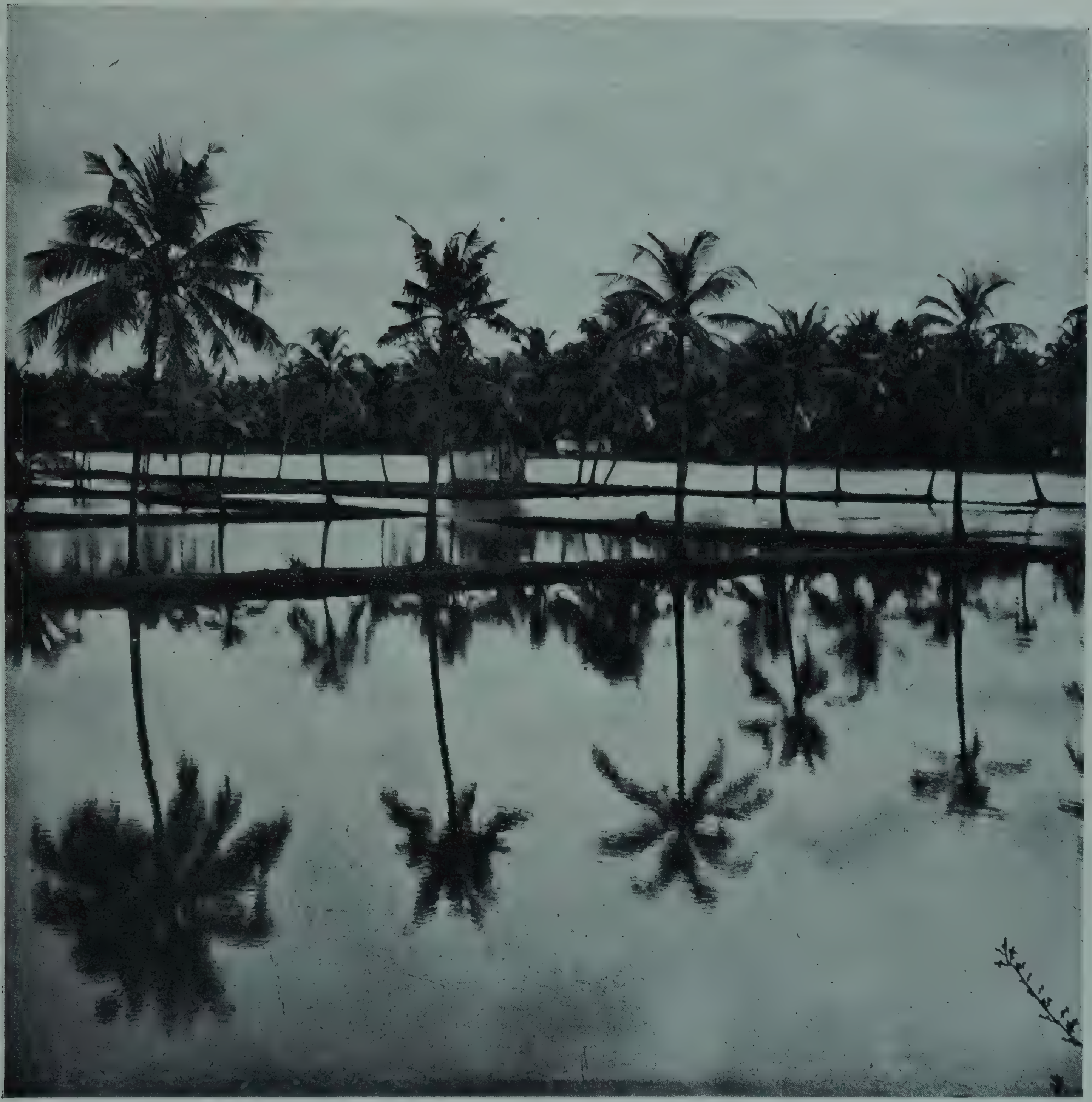

Fig. 45. Coconut palms growing on bunds

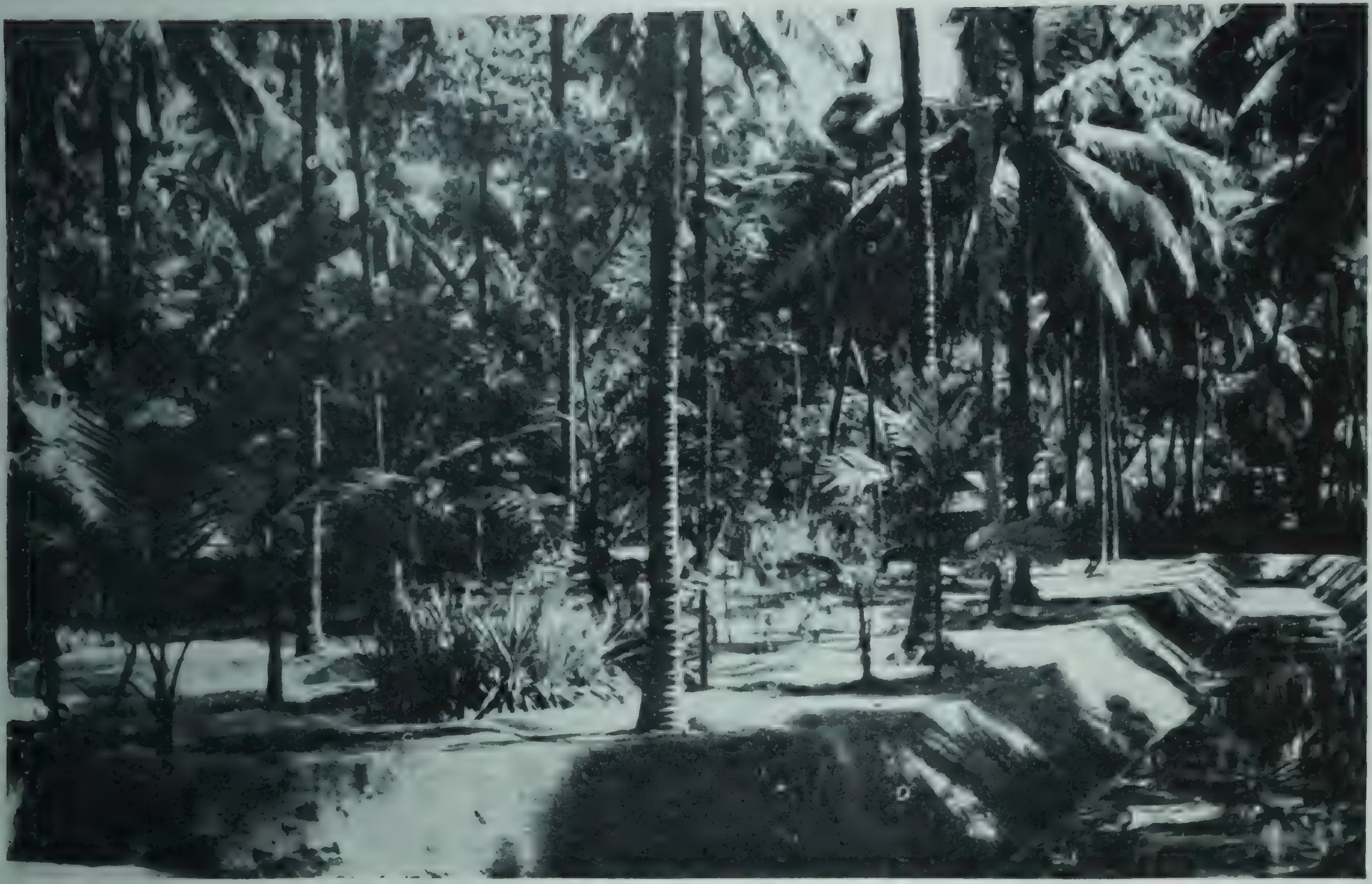

Fig. 46. Opening of drains in coconut gardens

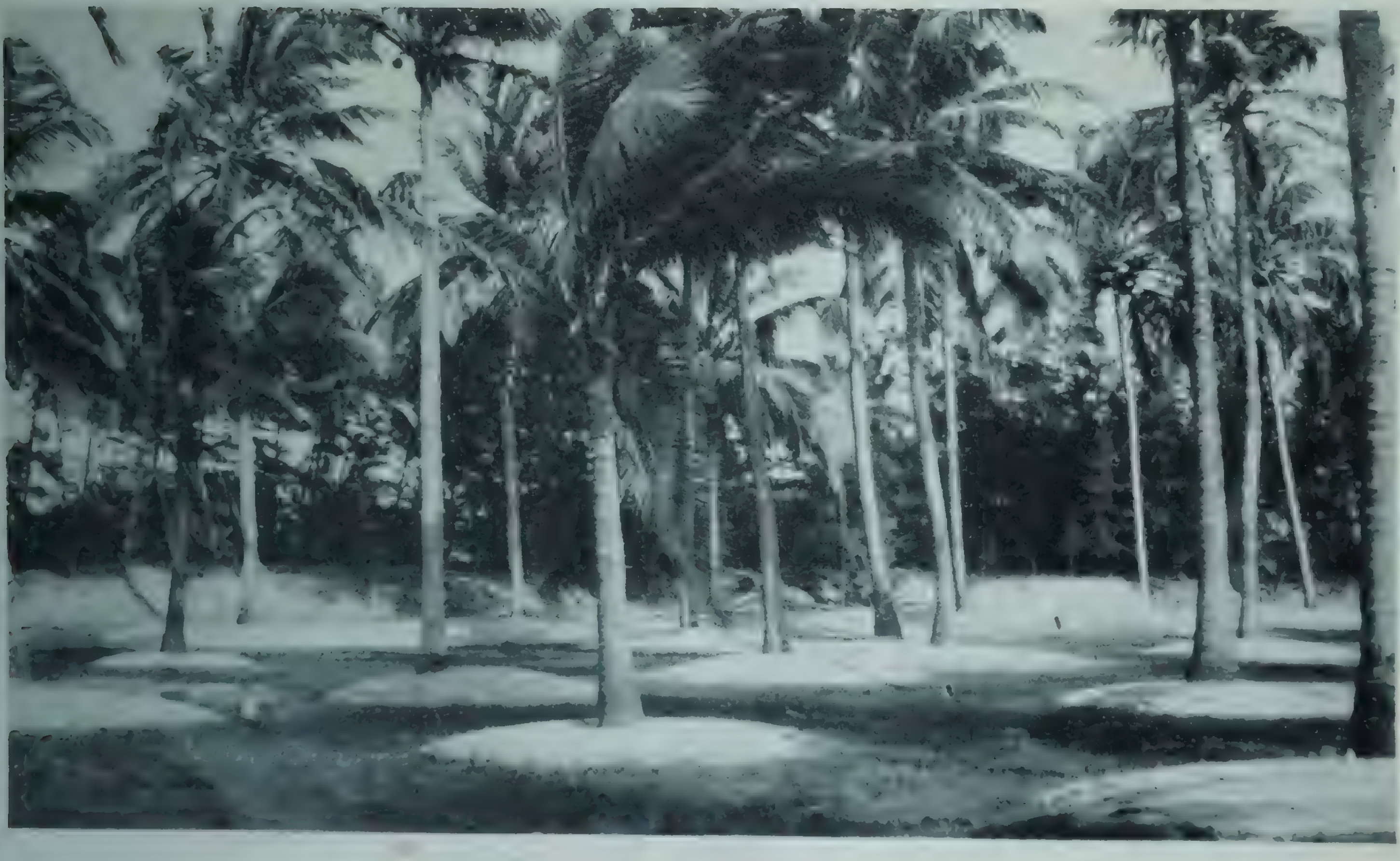

Fig. 47. Coconut palms growing in low-lying areas which are liable to flooding

The results more or less indicate that the coconut palm can adapt itself practically to all the different soil types for its growth.

The best soil, however, for the coconut, according to John (1949, 1952), is a rich alluvium or loam having proper soil moisture and drainage such as are met with in the backwater areas of Travancore-Cochin, Malabar, South Kanara and the deltaic tracts of the important rivers of India. The coconut also thrives and yields well in lateritic loamy, or black clayey soils on bunds of canals, channels or tanks and on the banks of rivers. It is also found to come up well on sandy soils especially of the littoral type, provided there is an assured supply of good underground water within easy reach of the roots and the trees are properly manured.

Coconut cultivation on bunds

In the backwater areas of Kerala it is customary to raise coconut plantations in made-up soils obtained by reclaiming the shallow submerged areas by applying clay and sand in alternate layers and raising the level of the land well above the water. Large areas exist and more have recently been planted with coconuts in the Travancore-Cochin area of Kerala on the reclaimed clayey soils and on *kari* lands. The *Kayal* or the lagoon areas are raised first by bunding, leaving alternate channels and coconuts are planted on the bunds. As these are made up of the silt and clay of the backwaters, the soil is fertile and palms thrive well even without manuring. Addition of sand also helps in improving the texture of the clayey soil. A possible deterioration often occurs but can be prevented by raising the level and filling up the alternate channels thus ensuring larger soil volume and facility for root spread. Menon (1954) and Nelliat (1956) have described details of this type of cultivation. More or less to the same type belong the acid peaty or *kari* soils met with in some parts of Travancore-Cochin. When dry, this soil is neither hard nor heavy like clay on account of the high organic matter content. These peaty soils are rich in plant food and the early performance of coconuts is very good on them. There are some of the best and largest coconut gardens on this type of soil in Travancore-Cochin (Fig. **45**).

Coconut soils and nutrient fixation effects

Some of the tropical soils observed in the different countries where coconut flourishes, have some inherent defects. Soils in which certain plant nutrients are ' fixed ' often turn out to be unsuitable for coconut growth unless methods to avoid or minimise fixation are adopted. Thus, the red lateritic soils which support a good majority of palms, are often found to be deficient in available phosphoric acid, potash, lime and nitrogen. Hydrated iron oxide which is a constituent of laterite soils has the property of ' fixing ' or locking up phosphoric acid in forms unavailable for plant use. Unless good decomposing organic matter is present and more of these fixed nutrients are constantly released, the palms will deteriorate on laterite soils especially when they are too shallow. The decline in growth of palms in laterite soils after an initial promising performance is usually due to this shallowness and the existence of hard pans just below the soil layer, which impede root penetration. Pits dug in the laterite area for planting receive 2 kg of common salt at the bottom for softening the rock to aid root penetration. Nevertheless, in the long run, coconuts cannot be expected to do so well in these soils as they do in the initial stages, unless adequate attention is bestowed for cultivation and manuring. However, large plantations in South India have recently been started on laterite soils.

A stiff clayey soil particularly with a stiff clay subsoil pan should as a rule be rejected. An important point in this connection is that well drained soils rich in humus but poor in clay tend to be deficient in potassium and consequently such soils are unsuitable for coconuts. Fixation of potassium by humus has not yet been proved satisfactorily. According to Pallmann *et al.* (1940) the organic matter of the soil actually possesses a great affinity for hydrogen, calcium and magnesium ions. Russell (1954) discussing the effects of soil forming factors on the potassium content of soils has said that, when illite type minerals are formed, there is a very powerful mechanism for holding potassium in the soil against loss by leaching and supplying it at a moderate rate for plant growth. When illites or other hydrous micas are not formed and when the silicate minerals in the sand and silt fractions have been decomposed, there is no mechanism left for supplying potassium after the exchangeable potassium has been used up. These conditions are invariably found in many sandy soil areas and should be expected in many well-drained and strongly leached soils containing kaolinite type of clay met with in the humid tropics. These aspects appear to be important since the coconut palm requires good amounts of phosphoric acid and potash for its nutrition.

Gravelly soils appear to be quite suitable for coconuts, provided leaching away of nutrients is prevented. Increased soil aeration in these areas and wide root spread enable the plant to secure food from a larger range. This often counter-balances the natural poverty of these soils. Addition of organic matter helps in their amelioration.

CHARACTERISTICS OF COCONUT SOILS

John and Menon (1947) state that a major portion of the coconut acreage in India lies in certain well defined zones on the west and east coasts and the tableland of Mysore, more than two-thirds of it being in the strip of land between the Western Ghats, and the Arabian Sea. Based on the soil, climate and certain other conditions under which coconuts are grown in India, the area can be grouped into the following well defined zones :—

(1) The coastal sandy tract with fairly high water table (1 m to 2½ m) of the West and East Coasts of the Peninsula lying mostly in Kerala, Madras, Andhra, Orissa and Bombay ;

(2) the clayey reclaimed areas of the backwaters of Travancore-Cochin and Malabar with high water table (1 m) ;

(3) the midland or the upland region lying between the coast and hill slopes of South Kanara and the Kerala area with sandy soil with low water table (about 6 m) ;

(4) the laterite and loamy soils of hill slopes of the West Coast with varying percentages of gravel and sand with low water table (about 6 m to 9 m) ;

(5) the sandy loam soils of Tanjore with high water table during rains and low water table in summer ;

(6) the alluvial deltaic soils of the Godavari ;

(7) the loamy soils of Mysore, lying at an elevation of about 600 m to 840 m and having a rainfall of 50 cm to 100 cm but with a fairly good supply of subsoil moisture ; and

(8) the forest soil of Andamans and the coral soils of Laccadives.

Sankarasubramoney *et al.* (1954) have carried out detailed studies of coconut soils in Travancore-Cochin. They find that coconuts grow quite well and yield well in the coastal soil, alluvial and loamy inland soils as well as on laterite and reclaimed soils. These authors (1952) and Pandalai *et al.* (1953) emphasise that with suitable cultivation, conservation, adopting ameliorative measures and manuring, all normal soils could be used for coconut cultivation. According to Nanjappa (1948), coconuts are grown in Mysore State either in gardens supplied by water from irrigation tanks or in wide shallow valleys or on river banks.

In the Philippine Islands, the soils vary from sand to clay. Cooke (1936) has compared the clay soils of this region with typical soil conditions obtained in Malaya, the sandy soils with certain regions in Ceylon and certain volcanic soils with similar ones in the South Sea Islands. The clays are regarded as the least suitable for coconut cultivation, the best being the light alluvial lime stone soils of river valleys and along the shores. Volcanic soils are also said to be highly suitable for coconuts.

Typical soil pH values are 6·2 for a poor yielding clay, 7·0 for a high yielding volcanic alluvium and 8·3 for a high yielding coral sand. Cooke (1936) gives the following percentage analysis of typically good and bad coconut soils situated within 0·4 km of each other.

	Clay	Silt	Fine sand	Coarse sand	Gravel	N	CaO	K_2O	P_2O_5
Coral sand (good)	5	5	60	19	8	0·06	13·0	0·17	0·08
Clay loam (bad) ..	25	29	33	6	..	0·13	1·46	0·58	0·09

According to Grange (cited by Eden, 1953), all the soils of western Samoa may be termed laterites and they are uncommon in that they contain from 7·8 per cent to 12·6 per cent of titanium oxide. The Samoan soil is very fertile even though old disintegrated lava lies either a few centimetres below the top soil or in jumbled masses on the surface. Coconuts grow there sending their roots through the surface lava and find rich deposits of soil in the lower and older lava flows.

In Seychelles, according to Durocher Yvon (1953), coconut cultivation is carried out on the two main soil types, the granitic and the coral. In the granitic islands, coconut plantations form a peripheral belt around the mountain massif, cultivation encroaching up the lower slopes. Some of the smaller islands are entirely planted up with coconut. The plantations comprise flat narrow coastal strips of coral sand of marine origin. This type of soil is very light, extremely friable and allows free percolation, with water table of 1½ m to 2½ m below. Fluctuations of the water table with the rise and fall of the tide coupled with the slow movement of hill side drainage water through the plateau are responsible for the optimum conditions. The alluvial plantations are on the richest soils but are only restricted in area, while the largest areas are on the sedentary laterite soils. These are not very good for coconuts, having lost their original structure through sheet erosion and offer minimum porosity, permeability and water holding capacity, physical conditions so detrimental to the coconut. In the coral type, the medium for coconut cultivation is formed of a coral sub-fraction covered with piled up sand of about 1½ m to 4 m deep, when the water table is invariably reached. The presence of natural deposits of sea bird guano rich in phosphates and other plant nutrients increases the fertility of these otherwise poor soils and accounts for the outstanding success of coconut cultivation in this group of islands.

Burcham (1947), writing on live-stock grazing on the Russell Islands says that there are several thousands of acres now under coconuts on the coastal soils which are shallow, recently weathered clays and clay loams, mixed with some loose coral and appreciable amounts of organic matter. In the Kedoe plain of Central Java, in southern Luzon and on the Coromandel coast of India, paddy lands and coconut groves are found interspersed. Some of the best coconuts thrive on such lands which are found to be most productive. This is due to suitable soil conditions besides getting plenty of sunshine.

In Malaya, on the west coast and in the inland areas, the crop is usually cultivated on heavy clay soils but on the east coast, however, cultivation is on sandy soils. The heavy soils are classed as clays (less than 20 per cent loss on ignition), organic soils (between 20 and 80 per cent loss on ignition) and peaty soils (over 80 per cent loss on ignition). A blue grey sticky clay commonly underlies all the soils. On the peaty and organic soils growth and yield depend to some extent on the distance of the mineral clay from the surface. Drainage is extensively practised on all soil types. The heavy clays respond well to drainage as they possess considerable permeability and being well supplied with nutrients, they do not require much fertilising (Belgrave, 1931). Smith (1932) has discussed cropping capacities of heavy alluvial soils in Malaya.

Wernigg (1932) has described the coconut industry in the Andaman Islands and finds that the soil is a rich clayey loam, fertile, but somewhat deficient in available phosphoric acid. However, after exploring the possibilities of coconut cultivation in the Andamans, John (1951) has reported that the soil and environmental conditions especially in the lower slopes of the hills and the land bordering the sea appear to be suitable for coconuts. The soils are virgin and therefore, of high fertility status. According to Albuquerque (1955), coconuts in the Car Nicobar Islands are grown on soils which are formed largely of decaying vegetable matter mixed with soft coral rock beneath. The soils are rich in many parts of the island with a high lime content. The water table is high being 2½ m to 3 m below ground level in summer. The rich soil and favourable distribution of rainfall make the island pre-eminently suitable for the coconut and large plantations are in existence along the coastal coral and sandy belts in all parts of the island. In Viti Levu in the Fiji Archipelago in the South West Pacific, coconuts are grown on different soil types " such as alluvial, terrace soils, rolling land soils, hill land soils and marine marshes " (private communication, 1956). Coconut soils in Trinidad vary from the sandy fringes of the beach to the heavy inland clays, (private communication from the Director of Agriculture, 1956). Coconuts in Thailand are grown commercially along the seashore and on islands in the Gulf of Thailand, while inland, it is grown on scattered areas for home consumption. Henderson (1956) has stated in a private communication that the main soil types on which the coconuts are grown in the territory of Papua and New Guinea are marine sands along the coast lines of the New Guinea mainland, volcanic pumic soils on the Gazelle Peninsula of New Britain and mature soils developed over coral in New Ireland.

In the Solomon Islands, the plantation areas predominate on coralline and igneous rocks (Pagden, 1936). The most consistently good estates are on the Russell Islands where the main soil type is a rich chocolate loam averaging about 1·8 per cent organic matter and pH ranging from 5·5 to 6·0 in the surface horizon. Less satisfactory growth is found on Malaita Island where the soil is heavy, often water-logged clay, containing for example 3·64 per cent organic matter and having pH value 6·9. Generally better basaltic or alluvial sands and loams occur in the neighbouring Guadalcanar Island. Pagden mentions an estate on very hard shelly limestone covered by only a few centimetres of soil which yields the astonishing crop of over a ton of copra per acre (Jacks, 1936).

Child (1955) records that in East Africa the soils are mostly sandy or sandy loam, low in organic matter. The pH values are mostly round about 6·0. The soils are deficient in phosphoric acid as well as potash. In the Quelimane coastal region there are many swampy areas in the depressions which are not really suitable for coconut cultivation.

Coconut cultivation in the Gold Coast is largely confined to a narrow coastal belt extending all along the sea board with the largest areas of cultivation at the eastern and western ends. In the Keta area, the coconut soils are largely coarse marine sands, light coloured and generally deficient in organic matter and derived from tertiary or recent formations. Coconuts are cultivated on the tidal clays in this area and these consist of light sandy clay top soil of high salinity overlying a black peaty subsoil. In the western province, the coconut soils overlie Appollanian (Cretaceous) formations, coastal coarse sand dunes, merging into a fertile coarse sandy loam, free draining and being ideal for coconut cultivation (private communication, 1956). Baldassari (1932) has described the soils under coconut in the Italian Somaliland. Pulgar Vidal (1953) states that in Columbian territories, particularly in the San Andes Archipelago, the most suitable soils for coconuts are volcanic or alluvial sandy soils of depth greater than 60 cm. A small proportion of ferruginous red clay is not detrimental but very clayey soils are not suitable.

Bunting (1930) has described the soil types in various districts of the northwest provinces of Ceylon as well as methods of soil cultivation and conservation practised there. Cooke (1932) lists seven common coconut soils, viz., red clay, loam, sandy loam, clayey sand, gravelly laterite, coarse sand and fine sand, all of which according to him are characterised by lightness and deficiency in humus and mineral nutrients. Coconuts are frequently cultivated in the higher parts of undulating ground, the wide intervening valleys being used for paddy. The soils are shallow and are underlain by rock. Upland soils tend to be more productive than soils situated near sea level owing, it is said, to greater movement of soil water in the former. Salgado (1950) has described river alluvium, estuarine deposits and limestone-derived soils to be good for coconuts, whereas laterite cabook, laterite gravels, cinnamon sands and estuarine clays are poor. The laterite soils are deficient in phosphoric acid and potash and moisture conservation is necessary on the laterite gravels. Cinnamon sands require conservation of organic matter and drainage facilities. The estuarine clays require manuring and deep ploughing and husk burying in order to make coconut cultivation economic on these soils.

Growth preferences

In spite of its wide adaptability to soil and climatic conditions as evident from the foregoing account, the coconut palm does show certain growth preferences. Anandan *et al.* (1950) have cited evidence to show that good growth of the coconut palm and high yields could be obtained only when it is raised under suitable soil conditions. A variety of factors including drainage, soil depth, layout of the land as well as soil fertility aspects are indeed involved and have pronounced influence on the growth of the palm.

Soil texture is a very dominant factor, good coconut soils being open textured to ensure a very extensive root system and good aeration. Deep alluvial loams and sandy terraces near the coast are particularly suitable. Near the sea, the ebb and flow of the tides produce movements in the subsoil water which appear to be ideal for coconut growth. This movement of water through the soil also takes place when well drained lowland soils are backed by higher ground as at the foot of hill or mountain slopes.

The land around the base of the mountains or hills whether near the sea or far remote from it, supports the growth of coconuts fairly well. Thus one of the largest coconut forests in the world is found situated surrounding Mount Banahao. Copeland (1931) states that in this district with only a few breaks between groves, there are more than ten million bearing trees. He has also said that the country around the foot of an old volcano is more certain to be suitable than that at the foot of mountains of other origin because the effluvium from volcano is usually porous. The water which falls upon it sinks more than the water which falls on ordinary mountains and comes back to the surface well charged with dissolved food from below.

Drainage

Facility for drainage in the soil is of primary importance. Sampson (1923) has dealt at great length on the effects of drainage on the root system and the general physiology of the coconut palm. Copeland (1931) as well as Sampson have stressed that the movement of soil water is most essential to ensure proper development and growth of the coconut palm. The coconut root is unable to withstand stagnant water whether it be sweet or saline. " Coconuts will thrive admirably well on the margins of well drained rice fields as well as close to the water-edge on a sandy sea-beach as this is influenced by the ebb and flow of the tide. Similarly along the banks of backwaters, lagoons and estuaries where there is tidal action and where the soil texture admits of free water movement, coconuts are found to do well. The coconut if given good drainage, is one of the most drought-resisting of trees. The essentials for natural drainage, therefore, are a free-working soil of open texture and either a deep water table or else free water movement through the soil ". Further, according to Sampson, a free-working soil of considerable depth and with good drainage even though of poor average fertility is much more desirable than a rich soil which has not got free drainage, either being too heavy or with too high a water table. Where drainage is defective, suitable drains should be opened (Fig. *46*).

Soil depth

The coconut palm requires a good soil depth. Even though the palm has an efficient root system, the roots are not strong enough to penetrate any hard layer such as a hard stiff pan of clay or hard laterite. Coconuts can flourish and yield normally with a very restricted root system provided the surface soil is physically suitable and chemically rich. However, Dwyer (1939) commenting upon the fall of mature coconut palms in New Guinea due to soil conditions, attributes this to a usually shallow friable top soil overlying a compact subsoil or in the presence of a high water table indicating that such soil conditions are unsuitable for coconut cultivation on account of root restriction. In Ceylon, Ganarajah (1953) recognises the necessity of at least 1 m of fertile soil for good and healthy coconut growth.

Soil fertility

An important factor orientating soil suitability for good coconut growth and high yields is tied up with the fertility status of the soils. According to Pandalai (1953), at least six principal factors condition the soil fertility aspects in relation to coconut cultivation, viz., soil moisture, soil nutrients including the major and trace elements, soil air, soil temperature, root space and the presence of injurious substances toxic to plant growth. All these aspects are discussed under appropriate headings. (Chapters VIII to X.)

Subsoil water as a source of nutrients

Copeland (1931) states that the main habitat of the coconut palm is one in which it draws its food not merely from the soil round about its roots but also from a moving body of water charged with nutrients continually coming to the soil from lands located above. This appears to be the case in several coconut tracts situated in the coastal belt. Soils which appear to be apparently poor from results of soil analysis and with a loose and porous texture, very poor in organic matter and with very low water conserving qualities often are found to serve as good medium for coconut growth. The coastal sandy tracts of Kerala are examples of this type and the trees there exhibit vigorous and luxuriant growth, probably because of the high water table conditions available in the area coupled with the excellent drainage facilities and nutrient-rich nature of the subsoil and subsoil water.

Usually coconut roots will not grow to any distance into water nor into a level of the soil where free water stands. A rise in the water level ultimately kills the submerged roots. In sandy soils, roots spread more widely both laterally and vertically than in heavy or stiff clay soils. It can be seen that this greater root spread enables the palm to gather nutrition from a larger volume of soil and more so in the case of the coastal sandy soils, where there are water resources charged with nutrient factors. Dwyer (1940) has described the same type of conditions and has, like Copeland, argued that palms may be expected to get such facility wherever there could be an underground seepage of water from higher hill slopes and soil formations further inland. Even under these circumstances, lack or exhaustion of nutrients will often be felt and then it has a much more pronounced effect where a restricted root system limits the total amount of moisture and nutrients available in an already deficient soil. In Witu Island, where the volcanic soils are very rich, the palms are found to thrive exceedingly well, even though the soil here is so shallow, being not more than 30 cm to 37 cm deep and roots stand on impervious volcanic rock which entirely restricts their growth below that level. The same is reported to be the conditions along the seashore of San Ramon.

Soils lacking in water holding capacity and suffering from excessive dryness or improper drainage are unfit for coconut cultivation. In other words, proper supply of soil moisture either through well distributed rainfall, percolation water or irrigation and sufficient drainage are essential for the coconut in addition to having a rich deep soil. Large-scale planting of coconuts should be undertaken only in lands satisfying these conditions.

Low-lying areas which are liable to flooding and which cannot be drained, should never be planted with coconuts. When there is a hard pan of clay cabook, limestone or slab rock near the surface, water-logging may occur during the rains, unless free subsoil drainage is possible. (Fig. *47*). The water-retentive power of gravelly and coarse sandy soils is low and as such the palms would suffer during droughts. Heavy clay soils, even though rich in plant foods are also unsuitable for coconuts in areas which are liable to drought effects. These soils are liable to shrink and crack causing extreme root damage thus cutting short the supplies of moisture and nutrients to the palms, particularly during long dry spells. Good coconut cultivation has, however, been reported in Malaya, Trinidad and other places, in heavy clay soils. Briton Jones (1928) has stated that it is generally true that the lighter soils in good tilth can support vegetation in a drier condition better than heavier soils in bad tilth. Soils with high water-holding capacity would naturally prove to be quite suitable for coconut growth. Cooke and Jagoe (1933) state that free water movement in the soil is very essential for good growth and the soil should not be allowed to dry up. These writers, however, are of the opinion that the best results were obtained on very heavy clay.

Selection of a site for a new plantation

The selection of a site for a new plantation is thus a very important problem. Obviously unsuited soil conditions should not prevail in the site selected. Any soil type with a definite history of coconut failure should be avoided. A preliminary soil survey should very much help in the matter and should include a detailed profile study. Soils liable to water-logging, such as low-lying swampy areas, stiff clayey soils with hard pans below, shallow layered laterite soils with hard rock beneath, etc., should not be planted with coconuts. Apart from soil suitability, one has to bear in mind, as Copeland has suggested, quite a number of aspects such as the climate of the region, the liability to danger from diseases, availability of labour, accessibility of supplies and markets as well as cost of the land.

It may thus be seen that quite an array of diverse factors govern soil suitability for good coconut cultivation. Many aspects are indeed involved due to the dynamic nature of the soil system and the heavy demand of plant nutrients of the coconut palm. The more the optimum conditions enumerated above are available, the more successful will be the coconut cultivation. At any rate, even if many of the above conditions are not satisfied, but judicious soil management and prophylactic measures resorted to, there is no reason why coconut cultivation should not prove successful and profitable.

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CHAPTER VII

PRODUCTION OF QUALITY PLANTING MATERIAL

Coconut is a perennial palm living for 80 to 100 years with an economic life of 60 years or more depending upon local conditions. The palm takes about 7 to 10 years to commence fruiting and another five years or more to come to the stage of full bearing. Thus, only after 15 or 20 years will the grower be in a position to reap the reward for his labours. If the original planting material used happens to be poor in quality, it will result in the establishment of a plantation giving poor yields and turn out to be a source of loss to the grower as long as the plantation lasts. There is nothing that he can do then to remedy matters except to cut and remove the unproductive and uneconomic trees. These facts will underline the need to plant quality planting material that will ultimately give good yields.

The coconut palm is a monocot and is capable of being propagated only through seed. As the palm is heterogeneous and cross pollinated in nature, the progeny is likely to be variable, but certain precautions, if observed, are found to help in the production of quality planting material. As a result of intensive investigations done in the important coconut growing countries of the world, it has been possible to fix criteria and to standardise nursery technique by which a large percentage of quality seedlings can be produced at relatively cheap cost. The following are the steps to be taken in this connection :—

1. Selection of seed centres
2. Selection of gardens
3. Selection of mother palms
4. Collection of seednuts
    - (*a*) Time of harvest
    - (*b*) Maturity at harvest
    - (*c*) Method of harvest
    - (*d*) Selection of seednut
    - (*e*) Preservation of seednuts
5. Nursery technique
    - (*a*) Selection and preparation of site
    - (*b*) Method of planting
    - (*c*) Spacing
    - (*d*) Depth of planting
    - (*e*) Time of planting
    - (*f*) Care and management of the nursery
6. Selection of seedlings
7. Removal of seedlings from the nursery
8. Age of seedlings at transplanting

SELECTION OF SEED CENTRES

In every country where coconut has been under cultivation for a long period of years, certain centres are found to have earned a reputation for the yield and quality of nuts produced there. There is always a great demand for seedlings from such centres for planting in the other parts of the country. In the important coconut regions of India a number of such centres of repute are known and the results of a critical and comparative evaluation of some of these centres in regard to the germination of seednuts and the outturn of quality seedlings from them have been reported by Aiyadurai (1954). Such studies will enable really good centres to be located for the large scale collection of seednuts.

SELECTION OF GARDENS

In the selected centres themselves all the gardens are not suitable for the collection of seednuts. Only those with a record of consistently high yields and containing a high proportion of heavy bearers and situated under average conditions without heavy manuring or irrigation and free from the incidence of pests and diseases are to be chosen. Coconut being mostly a cross-pollinated crop, this precaution is necessary to ensure that there is a greater chance of the female flowers of such palms being pollinated by pollen from heavy yielders. The nuts developing as a result of such pollination have a somewhat greater chance of producing superior progeny than others.

SELECTION OF MOTHER PALMS

Even in selected gardens, mother palms for the collection of seednuts have to be marked out on the basis of yield, copra content per nut, size and shape of nuts, nature of the crown, age of the palm, etc.

Yield

The annual yield of good ripe nuts is the most important criterion for the selection of mother palms. The trees should be regular and heavy bearers, i.e., they should yield heavy crops every year instead of in alternate years. In India, an average annual yield of not less than 80 nuts and preferably 100 nuts per tree is considered necessary for a mother palm. In Ceylon, the basis for the selection of mother palms is an annual yield of not less than 75 nuts with an average husked nut weight of 680 gm (*Leaflet* No. 1 *Coconut Research Institute, Ceylon*, 1954*a*). In Malaya, the requisite standard for selection is an annual yield of 100 nuts with a wet meat content of 500 gm each (Smith, 1933). As the number of nuts and weight of copra are highly correlated, there is little danger in taking the number of nuts produced as giving an idea of the copra yield, though the number of nuts and weight of husked nuts provide the best standards of selection (Pieris, 1934; Johns, 1938).

The most satisfactory way to judge the yielding capacity of a tree is to keep a complete and permanent record of nuts harvested from each individual tree at every harvest as is being done in some of the coconut research stations in India and the Coconut Research Institute of Ceylon. But this is neither possible nor practicable in the grower's holdings. However, as the palm bears a year's crop in its crown, the yearly yield of a tree can be roughly estimated by counting the nuts on the tree from the oldest to the youngest. To be really useful, such estimates should be made for a few even years and the average taken as the likely yield of the trees.

Certain characters of the coconut palm such as length of stem and number of leaves in the crown have also been shown to give an approximate idea of the bearing capacity of trees, provided the palms grow under similar conditions, receive identical treatment and are of the same age. High and significant correlations between yield and the above two characters have been obtained by Patel (1938). Pertinent data are given below:—

Table 28.—Correlation between yield and palm characters

Characters correlated	Total correlation for		
	1922	1927	1931
Total number of leaves and the yield ..	0·549 ± 0·052	0·598 ± 0·048	0·599 ± 0·048
The length of stem and the yield	0·517 ± 0·055	0·346 ± 0·067	0·425 ± 0·067

He has concluded from these and other correlation studies that:—

(*i*) The length of stem is an important criterion in finding out high yielding trees.

(*ii*) Total number of leaves is correlated with yield over a long period. A mature tree with large number of leaves would have yielded well in the past and is likely to yield well in the future also, provided the tree is not affected by old age.

A high yielding mother palm in its middle age will have at any time 30 to 40 fully opened leaves in its crown.

According to Sampson (1923) the trees that respond readily to a great extent to the changes in environment and manurial practices are also not desirable as these indicate a type which is genetically inferior. Inherently heavy bearers have not been found to respond markedly to ordinary manurial or cultural treatments.

Shape of the crown

The massive crown of the tree which is the most conspicuous part of the palm, is composed of leaves in the different stages of growth and spadices developing in the leaf axils. According to the disposition of the leaves in the crown it can roughly be grouped into four classes, viz., spherical, semi-spherical, drooping and erect. Among these, the first two are the best, as the disposition of the leaves is such that the bunches will have sufficient room for normal development and will be fully supported by the leaf petioles. When the crown is of the drooping type the bunches are likely to slip down, break the inflorescence stalk and shed the nuts in the immature stage. Trees with drooping or erect crowns should be avoided even if they show other desirable characters.

Nature of petiole and inflorescence stalks

The petioles should be short and stout and be able to give effective support to the coconut bunches. The bunch stalks should also be short and strong and not have any tendency to droop down. According to Pieris (1934), there is a highly significant and positive correlation between length of petiole and length of bunch stalk and this should make the selection of mother palms with these desirable characters easier.

Size and shape of nuts

Other conditions being the same, trees having medium-sized nuts with nearly round or spherical shape are better than the others for selection as mother palms. Such trees not only give high yields but the nuts also contain, in general, more copra than the others (Lacson, 1921 and Novero, 1922 cited by Maceda, 1933; Patel, 1938). That spherical nuts germinate earlier than others has been recorded by Maceda (1933) and Patel (1938). Smith (1933) got better germination from medium-sized nuts than from larger nuts.

Weight of bunches and nuts

There is some advantage in selecting trees which bear large number of heavy nuts in a bunch. Patel concludes from germination studies that a greater number of nuts from heavy bunches (twelve nuts or more) germinate much quicker than those of light bunches (six nuts and below) and that light seednuts (weighing 680 gm and below) give much reduced germination than heavy ones (weighing 680 gm and above). Umali (1940) has also come to similar conclusions. With some experience, light seednuts can easily be spotted out and rejected. Cox has also recommended this step (Patel, 1938).

Defective trees

Trees producing habitually barren nuts, i.e., nuts which are empty or do not contain well developed kernel inside or those that shed their nuts before they attain full maturity are to be discarded at the time of selection of mother palms even though such trees may give high yields.

Situation

Trees growing close to houses, cattle sheds, compost heaps, etc., may be avoided as it is difficult to differentiate under such conditions palms which are inherently good from those whose performance is solely due to the favourable conditions.

Age of the mother palm

There is some difference of opinion regarding the age of the palm to be selected for the collection of seednuts. Theoretically the age of the palm should make no difference on the quality of its offspring. In certain important coconut tracts of India, growers prefer to gather seednuts from old palms whose previous history they know well. Again, good palms have not infrequently been raised from seednuts gathered from young palms that have not reached the full bearing stage. Nursery studies done at the Agricultural Research Station, Nileshwar–III (India) did not reveal any difference among the seedlings raised from young, middle aged and old trees. One of the reasons for suggesting that middleaged trees are the best for selection as mother palms is that during that age, the trees will be in their prime of life and one can easily spot out really good yielders from mediocre or poor ones. If the trees are young or old, the assumption regarding their performance can very largely go wrong. This risk one cannot afford to take for reasons already referred to *in supra.* Under normal conditions, palms between 25 and 60 years of age would have reached the full bearing stage and can be selected as mother palms.

Mother palm nuts versus block nuts

Until recent years there was unanimous opinion among the research workers of different coconut growing countries regarding the need for selecting seednuts from high yielding mother palms that have other desirable characters also (Sampson, 1923; Mendiola, 1926; Copeland, 1931; Hunter and Leake, 1933; Smith, 1933; Pieris, 1934; Patel, 1938; Child, 1950 and John, 1952). However, of late, workers from Ceylon have questioned the necessity for mother palm selection and have stated that the system of selecting seednuts on ' Block nut ' basis is equally satisfactory (Cheyne, 1952 *a, b*; Liyanage, 1953 *a, b*). In this system the very best nuts are picked out from the heaps of nuts produced by the best ' blocks ' or fields of really good estates with consistent records of high annual yields and good copra production. The basis of selection is an annual yield of not less than 4,000 nuts per acre or an annual average of 55 nuts or more per palm (Cheyne, 1952 *a*). This practice has really emanated from the necessity to produce large number of seedlings in a short period which would not have been possible if the ' mother palm ' method of selection had been adhered to. It is admitted that first quality nuts come from 'mother palms' which give consistently high yields (Cheyne, 1952 *a, b*; Liyanage, 1953 *a, b*). The results of an experiment laid out at Ratmalagara Estate in Ceylon are adduced as evidence in support of 'Block nut selection '. Liyanage (1953 *b*) has particularly cautioned that failure to observe stringent standards of selection will largely reduce the efficiency of this method.

' Block nut ,' selection has one or two important draw-backs. One is that in most of the coconut growing countries, the industry is in the hands of peasant proprietors with holdings of very limited size and often in a neglected condition and with absolutely no records to go by. Contiguous blocks with records of high yield can seldom be found but outstanding individual palms can be easily spotted out and marked. Secondly, when selection of nuts is made from a heap, one has no knowledge concerning the good points or defects or the appearance and type of individual palms from which the seednuts are derived. Certain palms persistently yield large numbers of barren nuts or nuts of low germination and poor growth characteristics. Again, a poor palm may bear very few nuts of good shape and size which would be selected from a heap and thus perpetuated. The above are serious defects and only individual palm studies will enable such palms to be spotted out and discarded. Smith (1933) considers the method of selecting nuts from a heap as unsound in view of the fact that even in a plantation giving high yields, the proportion of really high grade palms is always very small.

The method of ' mother palm ' selection can be considered as an imperfect form of mass selection. As the male parent is unknown and the female parent is itself heterogeneous, there is no assurance that a genuine high yielding palm will reproduce its performance in the progeny. However, by this method there is a greater chance of obtaining a high yielding progeny than otherwise. Liyanage (1953 *b*) states that by ' mother palm ' selection alone 50 per cent efficiency can be obtained though it can be raised to 90 per cent or over by growing selected palms in isolation permitting natural inter-pollination between them. Jack (1930) has estimated that by ' mother palm ' selection, the first generation increase would be of the order of 25 to 35 per cent. In Ceylon, an isolated seed garden has recently been established from seednuts derived by artificial pollination between desirable palms (Liyanage, 1953 *a*).

The benefits of ' mother palm ' selection have been testified to by several workers. Cramer (private communication, 1951) states, " Many seedlings of the high yielding original mother trees have shown themselves good yielders and there is a great resemblance between the apparent descendents of the same mother palm ". Analysing the performance of progenies raised from high yielding mother palms selected for good appearance and high yield in native plantings, he found 17 per cent of the trees to give over 100 nuts per annum continuously, — a distinct improvement by selection. Dwyer (1938) has referred to a very interesting practical demonstration of the value of ' mother palm ' selection in the East Indies recorded by de Vear. Rockwood (1953) has claimed that the remarkable results obtained by him in his estate are due, among others, to the use of planting material derived from high yielding selected mother palms instead of from ' Block nuts ' of doubtful origin. In a trial laid out at the Nileshwar Coconut Research Station

(India) with progenies from different sources, there is indication to show that progenies from high yielding mother trees are better than those from poor yielding ones (Sayeed and Narayana, 1953). Though cent per cent purity cannot be expected because of the habit of pollination of the palms, up to 80 per cent is envisaged by Johns (1938). Dwyer (1938) also refers to an instance in British Guinea where ' palms have retained to a marked degree the original characteristics for which they were introduced '.

COLLECTION OF SEEDNUTS

(*a*) Time of harvest of seednuts

The proper time for the harvest of seednuts is likely to vary according to the seasonal conditions of the locality. The considerations that weigh in this connection are the general development of nuts, their capacity for germination, the period of storage required and the facilities for planting in the nursery. On the West Coast of India, seednuts are harvested in the months of February to May as these nuts are bigger in size, have the maximum copra content, give a high percentage of germination (95 per cent) and larger out-turn of good seedlings. This period also just precedes the South West monsoon so that, with the commencement of the rains, the nuts can be planted in the nursery which will have the advantage of the monsoon. Aiyadurai (1954), discussing the results of nursery experiments carried out on the West and East Coasts of India, concludes that the optimum period for harvest of seednuts may vary from tract to tract and that it has got to be determined for different localities with reference to the conditions obtaining there. Growers in some parts of India collect seednuts during some other months of the year also.

(*b*) Maturity of seednuts at harvest

The nuts to be utilised for seednut purposes are generally harvested only when they are fully mature, i.e., 12 months' old. Recent studies carried out in India and Ceylon have shown that the second bunch of nuts, i.e., nuts about 11 months' old can also be used for seednut purposes. There was no difference in the performance of seedlings derived from the two groups of nuts either in the earlier stages or at bearing (Liyanage, 1950).

(*c*) Method of harvest

It is generally recommended that seednut bunches should be cut and lowered by means of ropes to avoid damage that may result due to the fall of nuts from the crown. Studies have shown that except in places where the ground is hard or the trees are very tall, this practice has no special virtue or advantage. The bunches can be harvested in the ordinary manner.

(*d*) Selection of seednut

In addition to taking all precautions in the selection of mother palms and observing other factors mentioned previously, some sort of selection has to be done among the seednuts also. This is made necessary by the fact that in some bunches the development of nuts, particularly of those situated towards the top and bottom extremities of the bunch, is not always uniform. They may be undersized and relatively light. Such nuts do not germinate properly and have to be rejected (Fig. ***48***). The ventral or dorsal position of the nut in the bunch has no great influence on germination or seedling characteristics (Patel, 1938; Umali, 1940).

Some seednuts may show superficial cracks or other marks on them. In some others, the perianth may be found to get loosened and fall off easily at harvest time itself or during storage. These have no effect on germination of seednuts or on the subsequent growth of seedlings but such nuts are recommended to be avoided because of some other unfavourable effects they might have (Ummerkutty, 1955).

(*e*) Preservation of seednuts

The seednuts after harvest are not immediately planted in the nursery, but are generally stored in shade for about a month till the husk becomes dry (Fig. ***49***). On the West Coast of India, the nuts may have to be stored for a maximum period of about 4 months because though the seednut season starts in February, the nuts are planted in the nursery only with the break of the South West monsoon in June. During this period, which is the hottest part of the year, large numbers of nuts get dried up in spite of storing them in shade. Such nuts do not germinate at all or germinate very late and are therefore not fit for planting in the nursery. To prevent seednuts from drying up, John and Narayana (1942) have

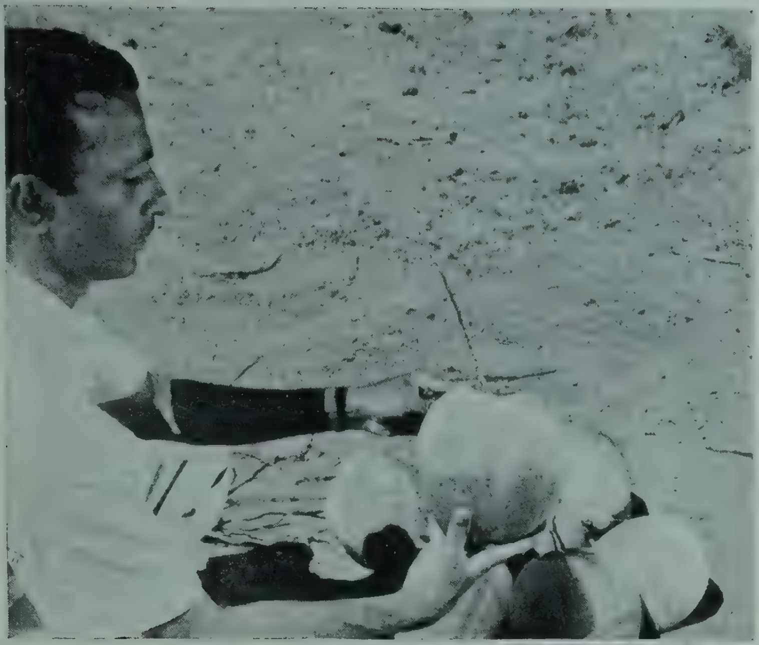

Fig. 48. Selecting seed coconut

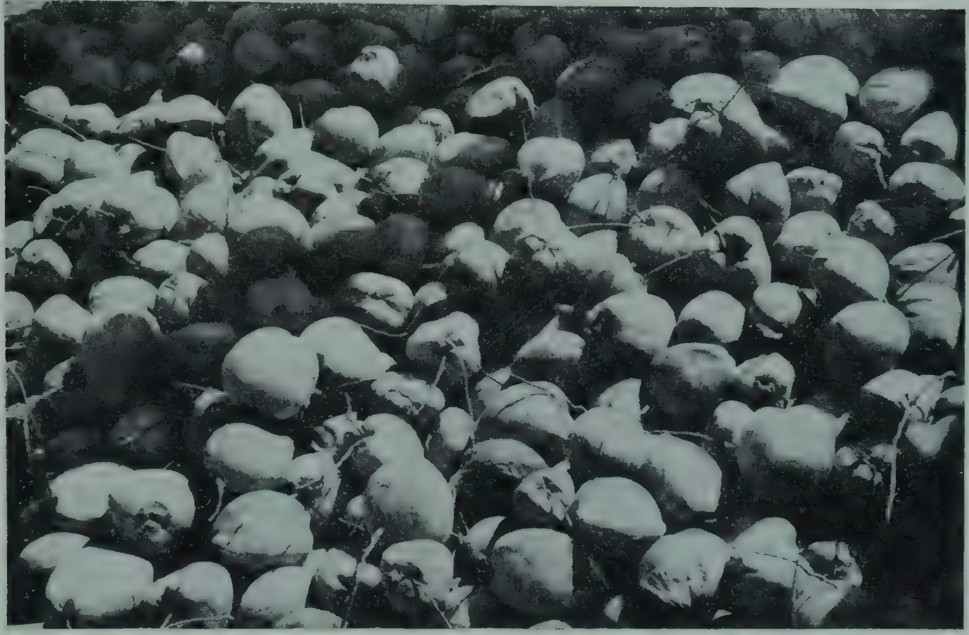

Fig. 49. Seednuts stored

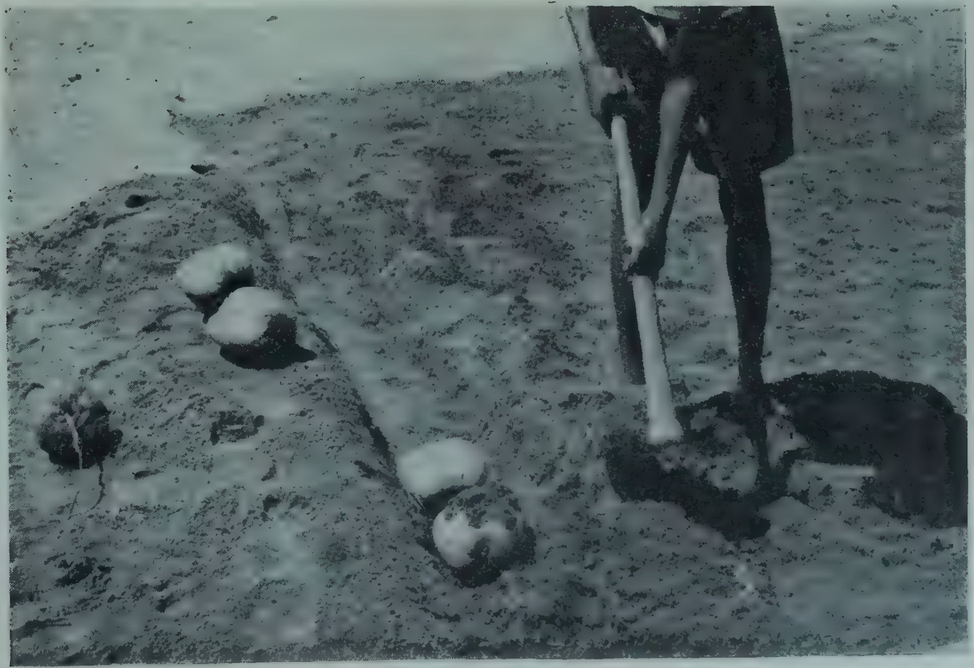

Fig. 50. Planting seed coconuts

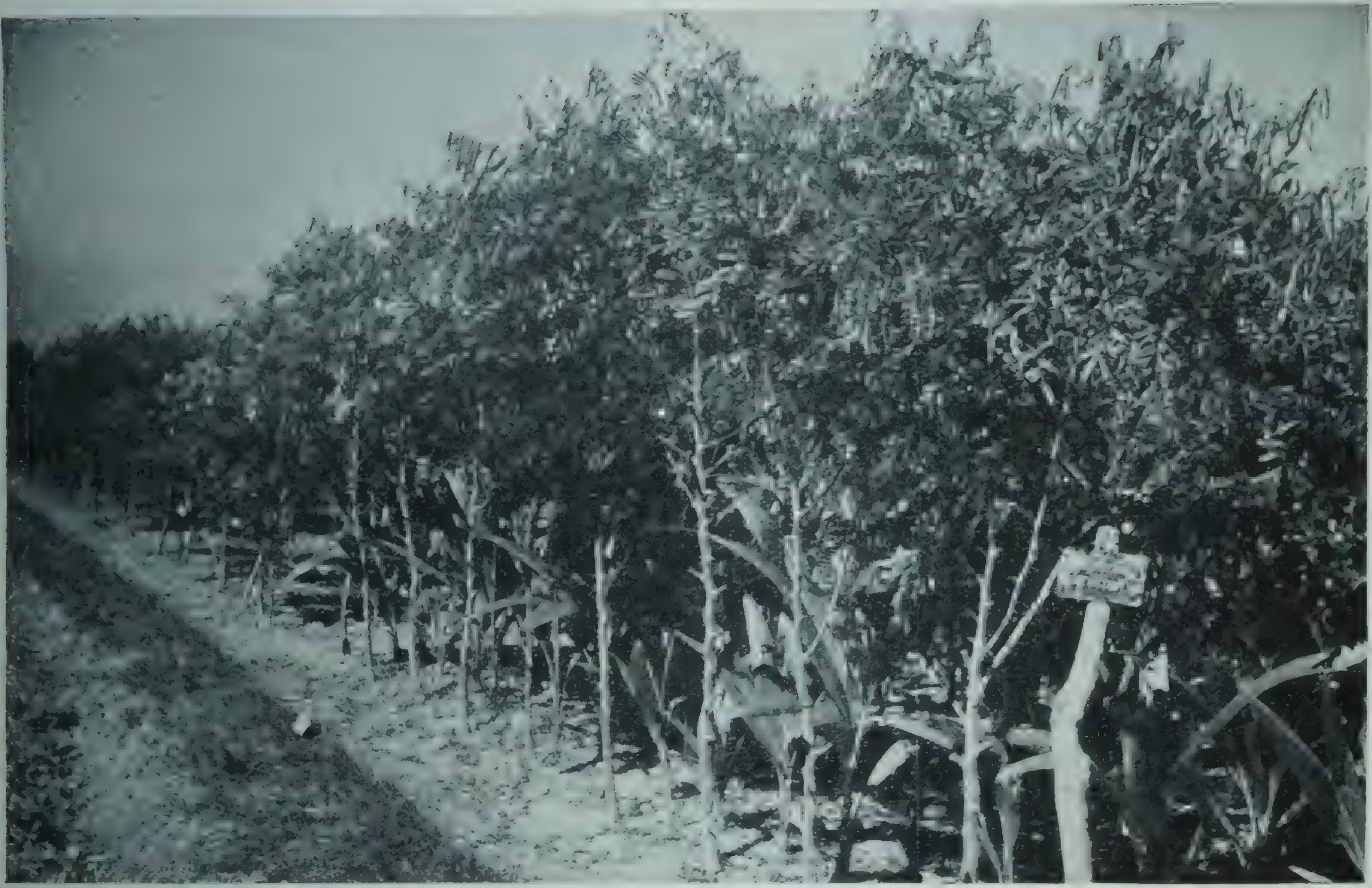

Fig. 51. Providing shade for seedlings in nursery

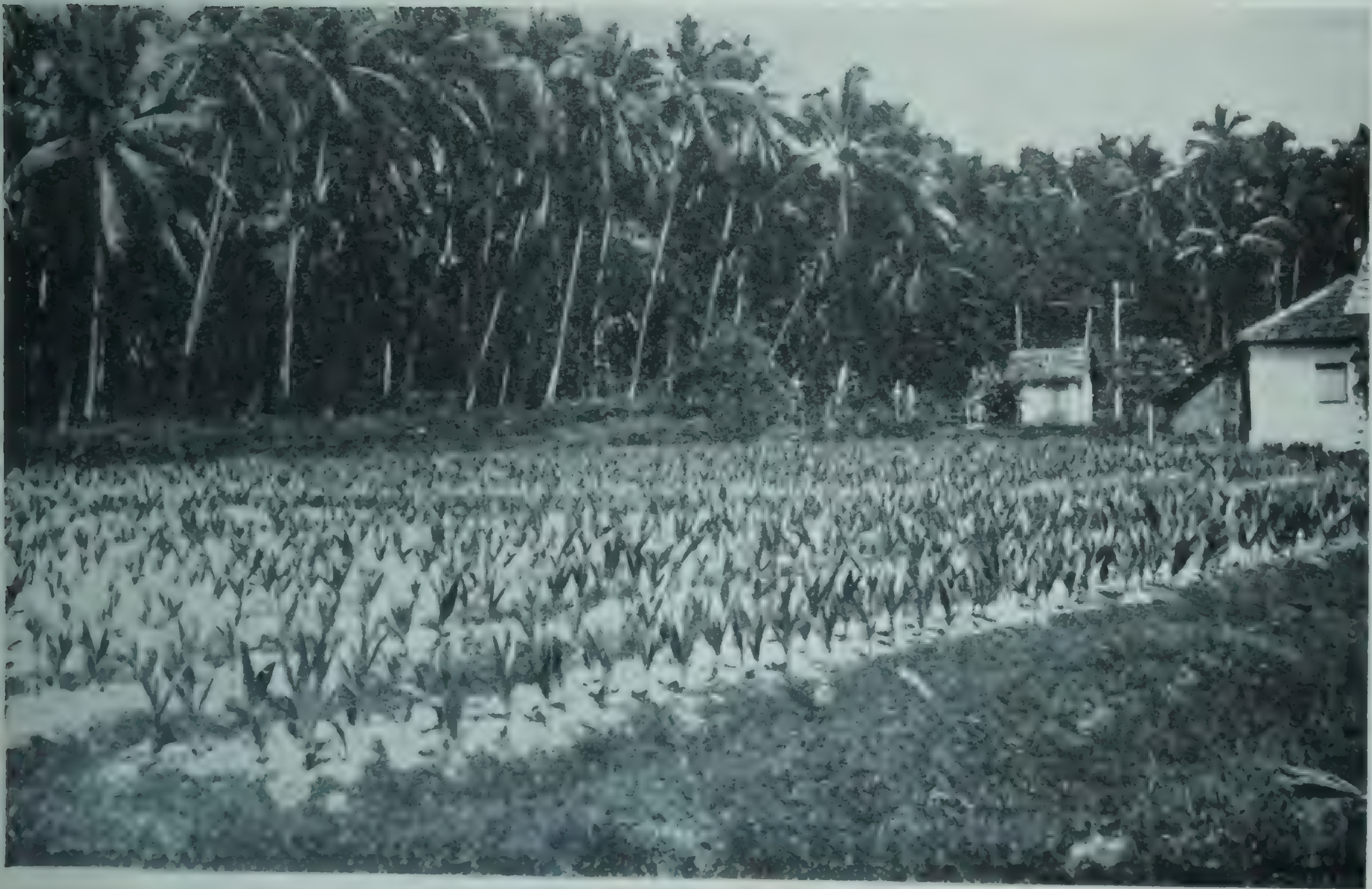

Fig. 52. Coconut nursery

recommended their preservation in fine dry sand. The seednuts are arranged with the stalk end up on the floor of a shed over a layer of about three inches of sand and completely covered up with it till the time of planting. Storage had no bad effect on the viability of seednuts or the quality of seedlings. This has been confirmed by Liyanage (1956).

NURSERY TECHNIQUE

Coconuts are not as a rule planted out directly in the field, since seedling selection, which has been established as an important factor in crop improvement is facilitated by planting seednuts in a nursery. Further, watering and controlling of pests and diseases in the early stages of growth can also be done more satisfactorily. The following are some of the odd practices followed by growers in the different coconut growing countries of the world for making the seednuts germinate.

(1) Seednuts are placed on the roofs of thatched houses during the monsoon and when they sprout they are directly transplanted in the field.

(2) The nuts are heaped in shade and allowed to sprout.

(3) The nuts are tied in pairs with a bit of husk split from each and then suspended from branches of trees or bamboo posts. Water is sprinkled over the nuts regularly till they sprout.

(4) In the Philippines, seednuts are tied round an upright pole in the open for germination.

(5) Sometimes the shed nuts are allowed to germinate where they fall.

The above methods are all defective. The nursery practices described hereunder are aimed at giving optimum conditions for the germination of seednuts and subsequent growth of seedlings with a view to obtaining a high percentage of selected seedlings from the nuts planted.

(*a*) Selection and preparation of site

The best place for a nursery is sandy soil located near a well or other water source to facilitate irrigation. In places where sandy soil is not available it is advisable to remove the soil to a depth of about 0·3 m to 0·5 m and fill it with sand. This will provide proper drainage and prevent termite attack which can cause serious damage to the nuts. The sand medium is also recommended because the growth of the seedlings will not be influenced by the fertility of the soil giving a better opportunity for a proper selection of seedlings to be made on intrinsic merit alone. In Ceylon, the nurseries are located on loamy and other soil types also. The nursery is best raised in the open, though it can be raised in the coconut garden itself provided there is not much of shade. Under heavy shade, the seedlings will have lean and lanky growth and unhealthy appearance.

The seed beds should preferably be long and narrow with provision for walking space or drains in between. The width is so adjusted as to take in 4 or 5 rows of nuts only. This will facilitate watering of the nursery and examination of seedlings from the sides without getting into the beds.

(*b*) Method of planting seednuts

Different methods of planting seednuts are in vogue. Some plant the seednuts horizontally while others plant them vertically with the stalk end up or in an oblique position. Some are reported to plant the seednuts even upside down. These methods have been subjected to critical examination and horizontal planting has been found to be the best (Espino, 1922; Ambrose, 1951; *Annual Report of Central Coconut Research Station, Kasaragod*, 1950-51). There is no particular virtue in sowing nuts in the same position as they float in water, as recommended by some. In horizontal planting, nuts should be placed with the widest of the three segments uppermost (Fig. ***50***). The soft or germinating eye lies below this segment and if planted in this position the sprout can easily come up. Sometimes other factors may also have to be taken into consideration in deciding upon the method of planting. Thus Huggins (1930) reports that in British Guiana, the ravages of the pest ' Cockles ' (*Strategvs aloeus*) is very serious in the nuts planted horizontally, while in the nuts planted vertically, the pest can be readily detected and controlled.

(*c*) Spacing of seednuts

The spacing of seednuts in the nursery is determined in relation to the time the seedlings have to be retained in the nursery. A spacing of about 25·4 cm to 38 cm from nut to nut will be quite convenient, if the seedlings are to be pulled out in about a year or a year and a half. In Godavari area and Orissa

(India), where much older seedlings are preferred for planting, it is usual to transplant the seedlings when they are one-year-old to a second nursery with a spacing of 0·9 m to 1·5 m between seedlings. In Ceylon, planting of nuts giving 22 cm spacing between the nuts in the row and between two rows is recommended (*Leaflet* No. 2, *Coconut Research Institute, Ceylon,* 1954 *b*).

(*d*) Depth of planting

The depth of sowing may be so adjusted that the husk appears just above the surface of the soil. Normally 15 cm depth would be quite sufficient. This depth has actually been proved to be the best in Ceylon from the points of view of total and early germination and out-turn of good seedlings. Surface sown (7·5 cm) seednuts suffered from desiccation and delayed germination while deep sowing (22 cm) resulted in delayed emergence of the sprout and unsatisfactory growth of seedlings. The delayed and poor germination of seednuts simply placed on the surface of the soil has been reported by Koating quoted by Patel (1938).

(*e*) Time of planting

The time of planting of nuts in the nursery will vary from tract to tract depending mostly upon the outbreak of the monsoon. By planting seednuts at the commencement of the rains, it will be possible to ensure optimum conditions for germination at very little cost, as otherwise, profuse and frequent watering has to be done in the initial stages. On the West Coast of India, nuts are sown in the nursery in May to June. At the time of sowing, it is necessary to re-examine the nuts individually and discard those which have dried up completely or have become rotten in the course of storage.

To promote better germination, methods like soaking of seednut in water, injection of major nutrients or of hormones have been tried. Soaking of seednuts in water for periods upto 15 days has been found to result in quicker and better germination, but if the period is prolonged, germination and quality of seedlings get affected. The effect is likely to be influenced by seasonal conditions also. If after sowing seednuts, heavy and continuous rains are received the difference may not be apparent, but if dry conditions were to prevail, the beneficial effect of soaking will be felt. Liyanage (1952) did not get any beneficial effects on germination by injecting six different kinds of hormones into the husk. Injection of major nutrients like N, P and K into the husk tried at the Central Coconut Research Station, Kasaragod had very adverse effects on germination.

(*f*) Care and management of the nursery

In the absence of rains, the nursery has to be watered twice a week or more often according to necessity. It is also to be kept free of weeds by periodical weeding. Heavy infestation of couch grass *Cynodon dactylon* is reported to have had a bad effect on the growth of seedlings in Ceylon. During dry and hot weather, the nursery beds should be mulched and shaded with dry coconut leaves or any other suitable material. Coconut leaf mulch has been reported to promote early and better germination, good growth of seedlings and to give high percentage of good seedlings (Liyanage, 1952; Verghese *et al.*, 1953; Aiyadurai, 1954). For providing shade without incurring much cost, the possibility of using some quick growing plants like *Sesbania speciosa* has been indicated by Aiyadurai and Mohammed Ibrahim (1954), (Fig. *51*). Sampson (1923) and John (1952) are not in favour of applying manures to the seedlings in the nursery as they feel that the intrinsic quality of the seedling is likely to be masked to some extent making a proper selection of seedlings difficult. Nursery manuring is however, recommended and practised in Ceylon (*Leaflet* No. 2, *Coconut Research Institute, Ceylon,* 1954 *b*).

A careful watch must be kept for the incidence of pests and diseases so that proper control measures can be taken promptly and in time. Serious damage is likely to be caused by termite attack against which BHC or DDT formulations can be used with success. The need for taking care in their use is however, indicated because of the reported depressive action of the insecticides on the growth and general condition of the seedlings in the absence of termite attack (Aiyadurai, 1954).

SELECTION OF SEEDLINGS

Under favourable conditions of environment, the nuts of the tall variety of the coconut will commence to germinate 11 to 12 weeks after planting. The percentage of germination reaches the maximum between the 17th and 18th week and then commences to decline. In India, nuts which do not germinate within 6 months from the date of planting are removed from the nursery. Fig. **52** gives a general view of the nursery and Fig. **53** shows seedlings in different stages of growth.

In view of the lack of genetic purity in seednuts, vigorous roguing out of inferior seedlings in the nursery is as important as the selection of mother palms and seednuts. Research workers in Ceylon consider this step as the most important in the production of quality planting material. Liyanage (1953 *b*), analysing the results of a field trial laid out in Ratmalagara Estate (Ceylon) to study the comparative effects of selection of mother palms and seedlings comes to the conclusion that selection of seedlings alone will increase the crop by 10 per cent.

Selection of seedlings in the nursery is based on characters which are believed and in some instances actually proved to be associated with good yield in the adult palms such as early germination, rapidity of growth, early splitting of leaves into leaflets, vigour, sturdiness and freedom from pests and diseases.

Early germination

This is a very important criterion for seedling selection. It is not dependent upon the date of sowing. Early germinated seedlings grow faster, a negative correlation of $0 \cdot 609 \pm 0 \cdot 014$ having been obtained (Patel, 1938) between the number of leaves produced and the time taken for germination. Correlation studies also show that the palms with larger number of leaves begin to flower earlier than those with smaller number of leaves. It is therefore to be expected that early germinated seedlings will flower early. Jack and Sands (1929) and Liyanage (1955 *a*, *b*) have come to the same conclusion. The latter got a highly significant positive correlation of 0·437 between sprouting of seednuts and flowering of palms and a negative correlation of 0·424 between sprouting and yield, showing thereby that seednuts sprouted early give rise to palms that flower in a shorter period and are more productive than those sprouted later.

Vigour in seedlings

This is indicated by the vegetative characters relating to growth such as number of leaves, height of leaves and girth at collar, the combined effect of which is reflected in the weight of the seedlings. All these characters are found correlated with the weight of seedlings but girth at collar appears to be more important than the height. Another sign of vigour in the seedlings is early splitting of leaves into leaflets (Fig. ***54***).

Selection of seedlings should therefore be restricted to healthy, vigorous, robust looking ones possessing large number of leaves with short and thick petioles, good girth at base and large number of roots. Unhealthy seedlings with poor and stunted growth and those that are thin and easily susceptible to the attack of pests and diseases should be rejected. By adopting vigorous standards of selection, about 40 to 50 per cent may have to be discarded. Thus, the number of nuts to be planted in the nursery should be nearly twice the number of seedlings actually required. The rejected seedlings do not represent a dead loss since some copra can be recovered from them (Child and Nathanael, 1947). The non-germination of seednuts may be due to the damage to the embryo caused by insect pests or fungus and in rare instances to the absence of the embryo itself.

REMOVAL OF SEEDLINGS FROM NURSERY

After selection, the seedlings should be removed from the nursery only just before they are required for transplanting in the field. These seedlings should not be pulled out by force, but their roots should be neatly cut and the seedlings with the nuts gently removed. Pruning of roots is not harmful in younger seedlings (7 to 12 months old) but may cause some delay in establishment and retard the growth of older ones (Patel, 1938). The seedlings pulled out of the nursery should be planted as early as possible, preferably before 10 days (Aiyadurai, 1954).

AGE OF SEEDLINGS AT TRANSPLANTING

From what has been mentioned previously, it is clear that systematic selection of seedlings in the nursery is indispensable if one is to expect good performance from the future plantations. Such selection is possible only when the seedlings are at least 9 to 12 months old. In Ceylon, selection is done when the seedling has developed about three green leaves (*Leaflet* No. 2, *Coconut Research Institute, Ceylon*, 1954 *b*).

As a general rule, under ordinary conditions, seedlings 9 to 18 months old can be considered the best for planting out in most places. At this stage they will have about 60 per cent of the kernel still left in the nut as an available food reserve for the growing seedling and this will facilitate their quicker establishment when transplanted out in the field. These seedlings do not wither quickly and being light in weight, are also easy and cheap to transport over long distances.

In Tanjore (India), there is a practice of planting in the field nuts that have just sprouted and known as *Kakka Mooku* (Crow's beak) (John and Menon, 1947). Though establishment of such a seedling is quicker, this practice is undesirable in that : (*i*) no proper selection of seedlings can be done, (*ii*) the seedlings would require greater attention by way of watering, protection, etc., for a longer period of time in the planted field and (*iii*) may succumb to unfavourable conditions such as water-logging, etc. Espino (1922) recommends the planting of seedlings which are not more than a foot in height.

Three to five-year-old seedlings are planted in some parts of India such as Godavari, Mysore and Orissa. The reasons given in support of this practice are : (*i*) the aged seedlings suffer less from the ravages of cattle, (*ii*) being heavy, they are not likely to be uprooted by heavy wind or water current during the rainy season. The disadvantages are : (*i*) the seedlings will require heavy watering in the rainless months, and adequate propping in the initial stages, (*ii*) because of the inevitable heavy damage to the root system, many seedlings fail to establish properly and (*iii*) transport is difficult and costly.

In low-lying fields subject to water stagnation, two-year-old seedlings are preferred for planting.

ACCLIMATISATION OF PALMS

Some coconut growers are of the opinion that the palms get acclimatised to restricted environment and develop ecotypes and that for raising successful plantations in a particular area, the planting material should be obtained from areas similar to it in soil and climatic conditions. It would thus mean for example, that seedlings for planting in sandy coastal tracts, and interior lateritic regions should be obtained from corresponding areas only. Sampson (1923) has subscribed to this view from a study of the root system of the coconut palm. There is no definite experimental evidence on a field scale to support or refute this opinion, but the fact that thousands of seedlings distributed without any consideration to this aspect are being grown in the different coconut growing countries without any adverse comment, suggests that this factor may not be of much consequence in practice. An experiment designed to compare the performance of planting material derived from palms growing in (*a*) sandy loam overlying laterite and gravel, (*b*) sandy loam of considerable depth and (*c*) clay loam overlying clay and planted in one and the same site is reported to have been laid out in Ceylon *(Ann. Rep. Coconut Research Scheme for 1943)*. Instances have, however, been recorded wherein varieties introduced from one country to another have failed to show their original form under the new environment. A much quoted example is the failure of the famous San Blas coconut of Panama to live up to its reputation when introduced into Malaya.

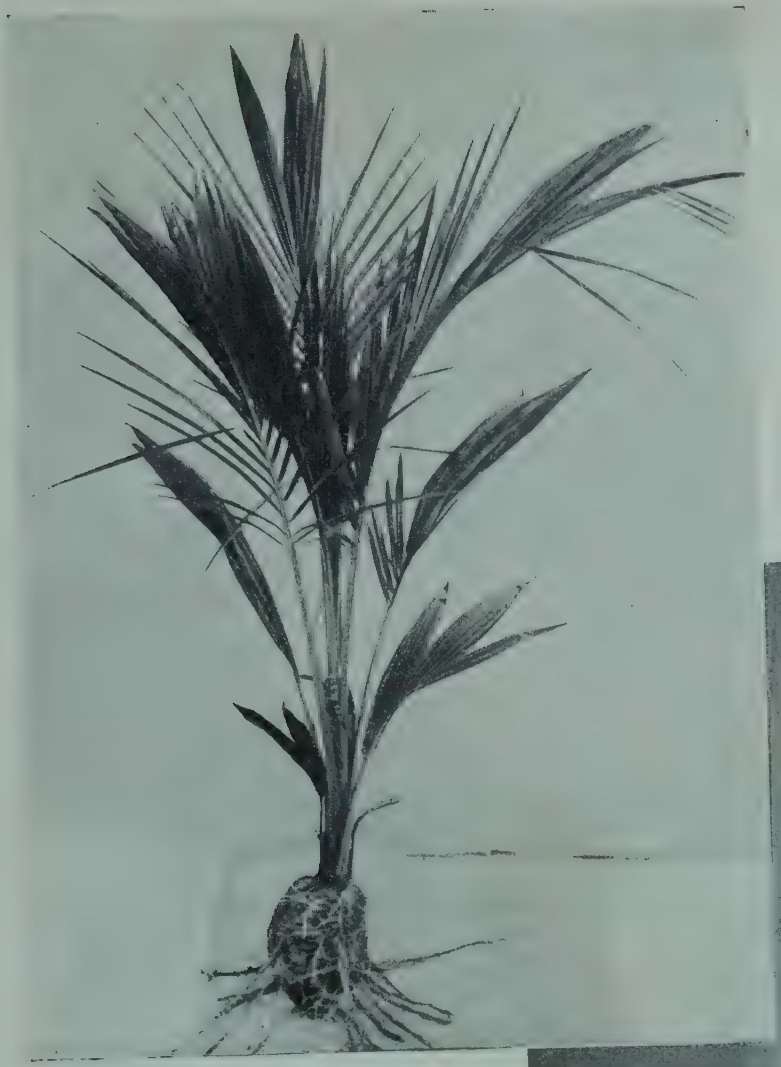

Fig. 54. Early splitting of leaves

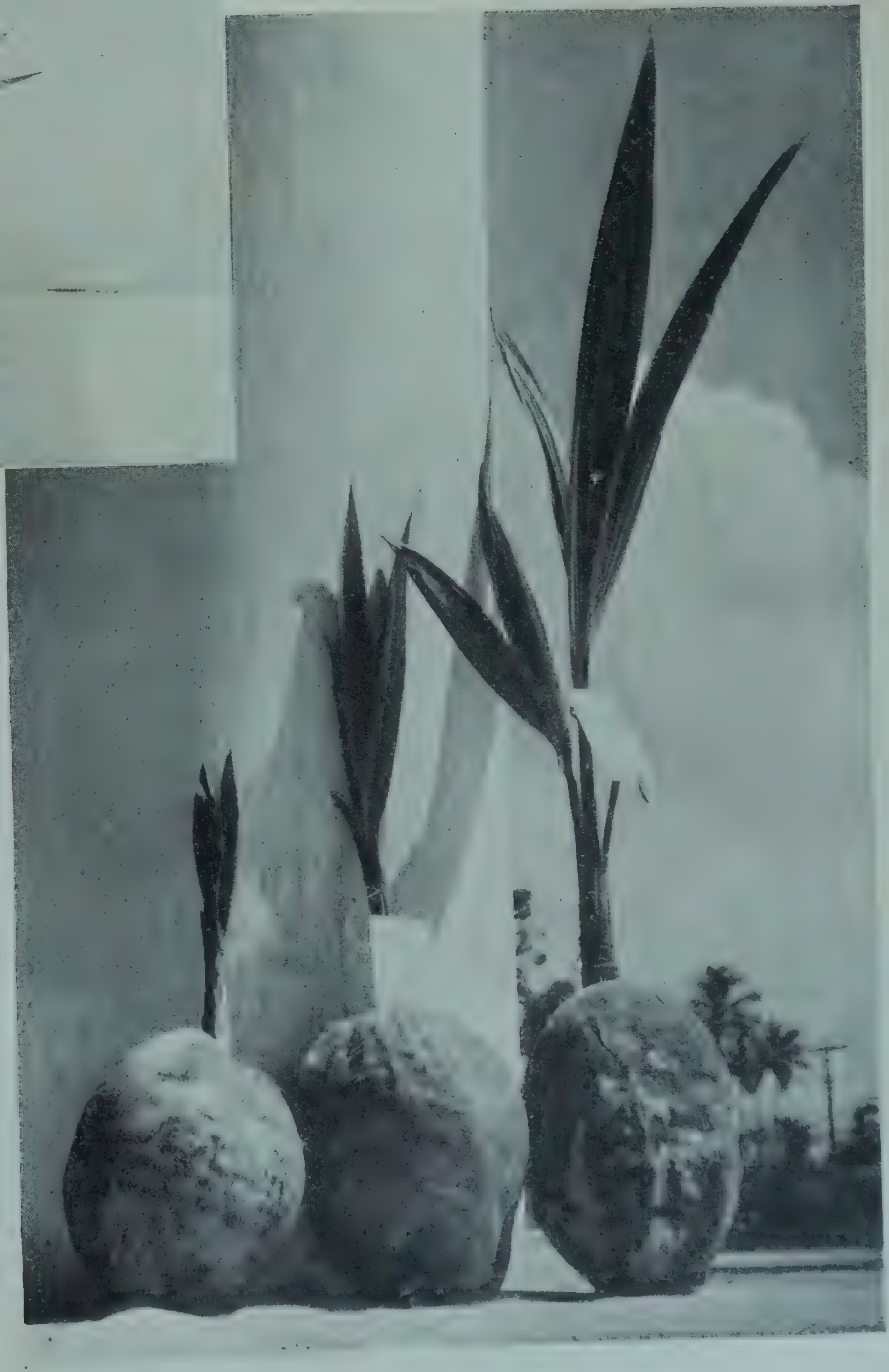

Fig. 53. Seedlings in stages of growth

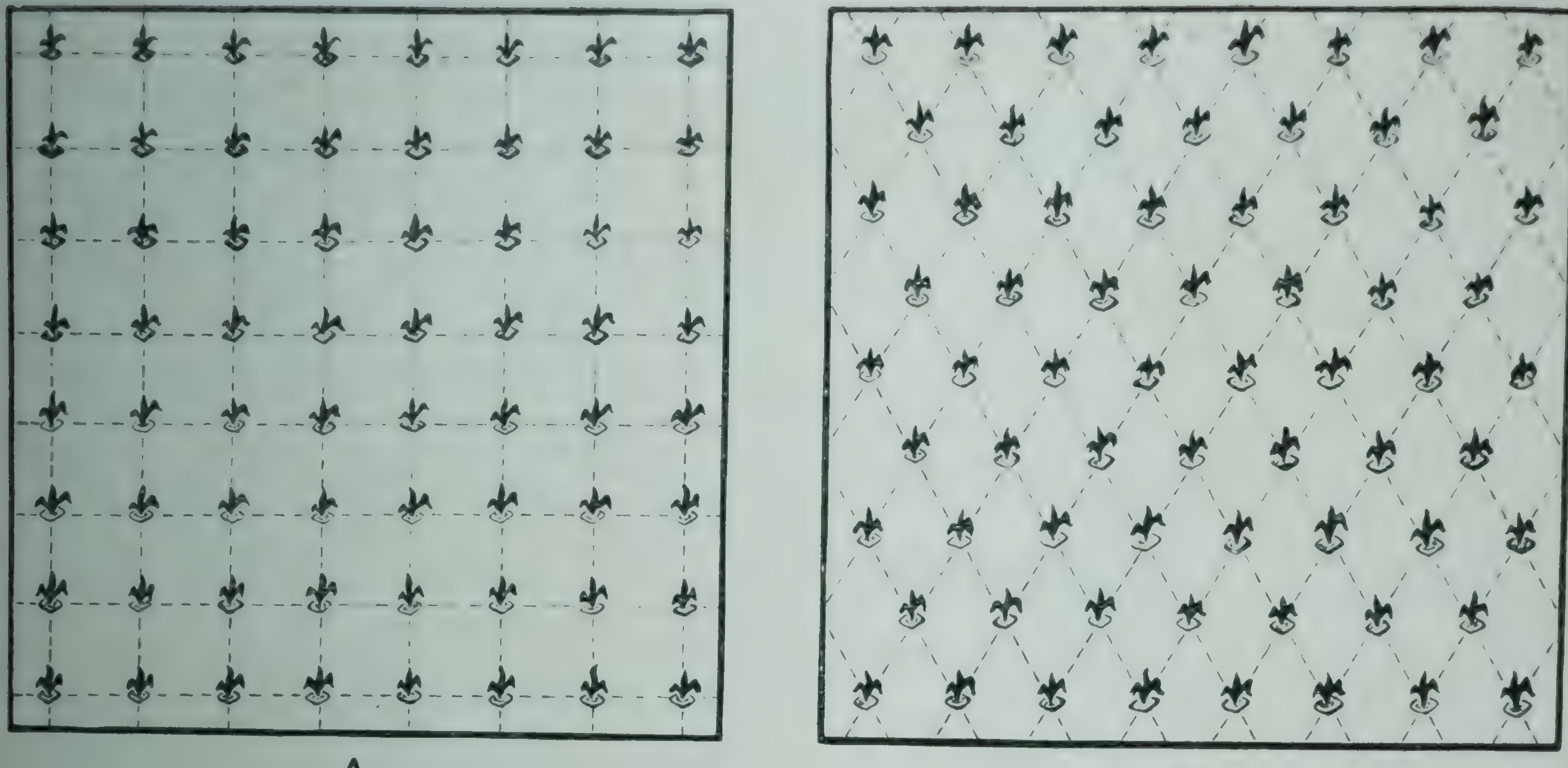

Fig. 55. Two common systems of planting coconut seedlings
A. Square system ; B. Triangular system

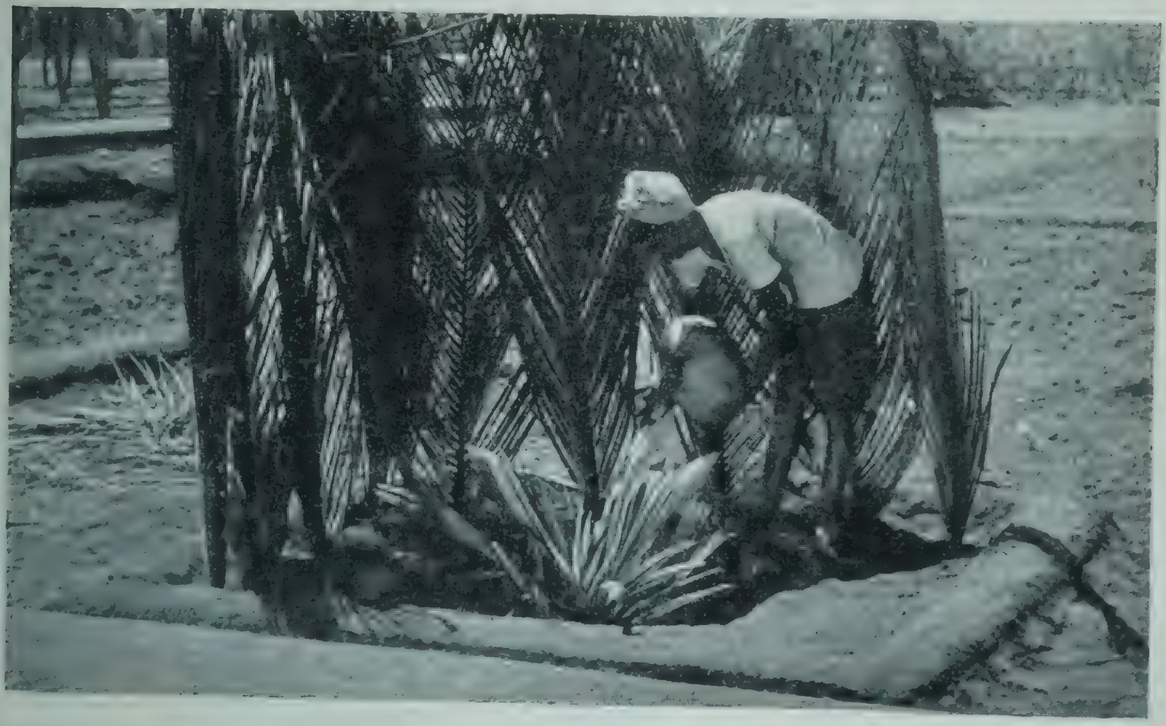

Fig. 56.
Shading
seedlings
with
coconut
leaves

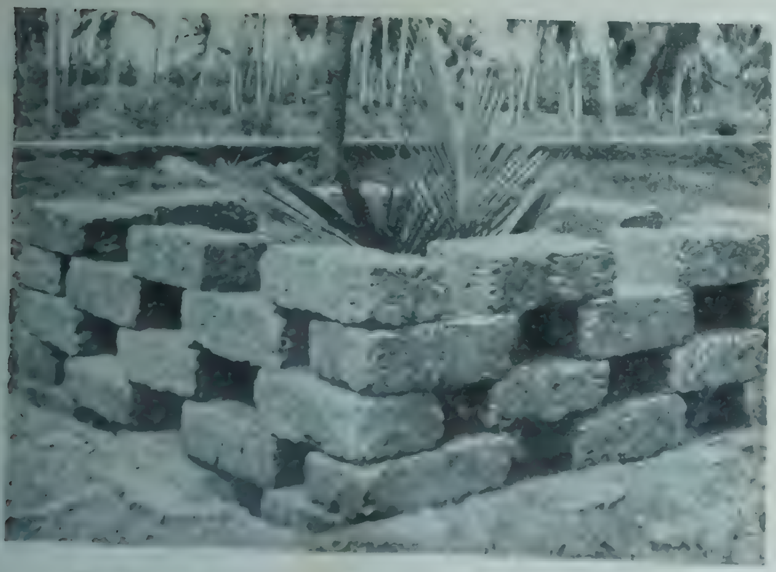

Fig. 57. Fencing seedlings with laterite bricks

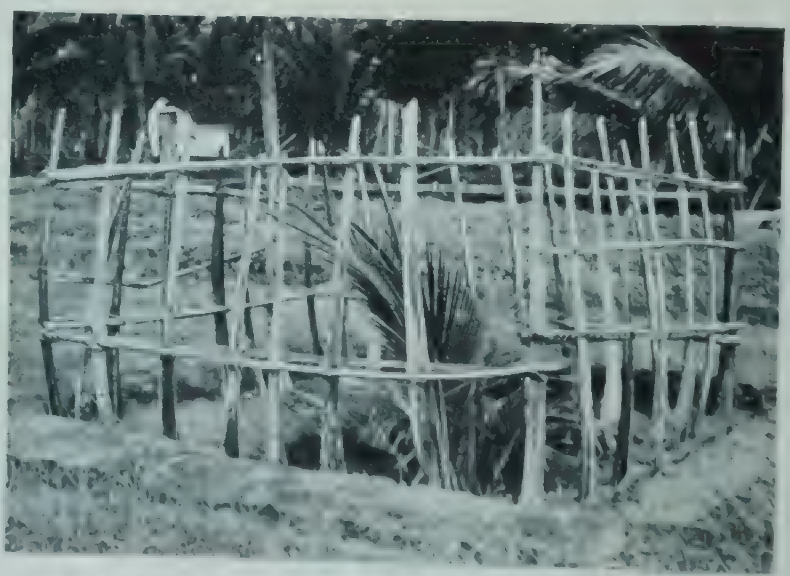

Fig. 58. Fencing seedlings with coconut petioles

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CHAPTER VIII

FIELD CULTURE

STARTING OF A PLANTATION

Before starting a coconut plantation, the greatest care should be taken to see that the climatic and soil conditions obtaining in the area are suitable for raising the crop. When once that has been decided, the sequence of steps to be taken is the following :—

Preparation of land for planting. The preparation of the land will depend upon its situation and condition. If the land has already been cleared and is under cultivation, no special preparation may be necessary. If the land is virgin jungle or under scrub growth, the trees and shrubs have to be removed along with the stumps. Because of the accumulated debris out of fallen leaves, termite attack might be expected and so the land may be ploughed up and a cover crop raised for two or three seasons.

If the land is sloping, it is necessary to terrace it properly and take anti-erosion measures to prevent loss of surface soil during rains. Methods for effecting soil and water conservation on lands not yet planted have been described in detail by Gorrie (1950) and Fredrick (1953). In low-lying areas where water is likely to stagnate, drains should be cut and the area drained properly.

In low-lying and backwater areas, in the south of Kerala State (India) where the water table remains high throughout the year, coconuts are planted on raised bunds. These bunds may be from 5 m to 8 m in width and are built up by dumping clay and sand in alternate layers inside enclosures made by stone revetments. Bunds are also formed with soil from the adjacent strips of land either with manual labour or with the help of a dredger.

Fencing. The land to be planted with coconut should be fenced properly even at the very outset. It is sheer waste of money and resources to plant seedlings without providing them adequate protection from stray cattle. In parts of the West Coast of India, earth walls form very effective barriers against cattle. Live fences are also largely in vogue, but they are only of temporary nature and require periodical renewal to keep them in effective condition. In Ceylon, barbed wire fencing is largely in use.

Spacing. After the land is got ready for planting, the next step is to peg mark the sites where planting holes are to be dug. Sites very near stumps of trees which have been previously cut down should be avoided.

In the different coconut growing countries where the majority of holdings are small and under peasant ownership, the growers often plant coconuts haphazardly without adopting any proper spacing or system of planting. Closer planting and growing other kinds of trees also mixed with the coconut are common. The tendency towards overcrowding is mainly due to the fact that valuation of land is based on the number of trees present and not on their yield.

The spacing actually adopted is found to vary from country to country and in the same country from region to region. In India, the spacing varies from 6 m to 9 m or more though 7½ m to 9 m is now recommended for average conditions. It is reported that in Ceylon (Pieris, 1945), coconuts are planted as close as 2·75 m or as far apart as 14 m the more common spacing being 8 m to 8·7 m. A spacing of 8 m is now recommended for most conditions in Ceylon. The spacings adopted in some of the other countries are : Malaya, 9 m; Indonesia, 10 m to 11 m; Seychelles, 9 m to 10 m; Trinidad, 7·7 m; British Guiana, 9 m.

In deciding upon the optimum spacing, some important factors have to be taken into consideration. One is that adequate room should be provided for the roots to develop properly. It is only reasonable to suppose that depending upon the soil and climatic conditions there exists a definite number of plants per acre which will give maximum yields from a given piece of land. If the stand falls short of the optimum, production is diminished owing to the fact that full advantage is not being taken of the available area. On the other hand, if the stand is excessive, the yield will be diminished owing to overcrowding and consequent intense competition between palms for plant food, moisture, light and air. Under conditions of close planting, there is a tendency for the palms to grow tall and lanky in their struggle to get sunlight and considerable energy might be lost in producing a tall trunk at the expense of yield.

Conditions of the soil such as depth and fertility also have some influence on spacing. Light soils offer less resistance than heavy soils to the penetration of roots, which consequently spread to larger areas. Briton Jones (1940) recommends that where the depth of soil is for one reason or another, restricted, wider spacing should be given between palms so that the volume of soil available for exploitation by the roots is not unduly diminished. Regarding the spacing to be adopted in soils of different fertility, there appears to be some differences of opinion. In Ceylon and the Philippines, in fertile soils, only fewer numbers of palms are recommended, while Patel (1938) and John (1952) suggest that such areas can carry larger number of plants than otherwise. The recommendation of the Department of Agriculture, Jamaica is in line with the latter point of view.

In Ceylon, for areas subject to drought conditions, close planting of coconuts is advocated (Ganarajah, 1954), the argument in favour of it being that under such conditions, the soil will be adequately shaded by the overlapping fronds of adjacent palms, thus preventing soil desiccation and loss of moisture. This point of view is however, questioned by Briton Jones (1940) with the remark: " that the deep shade under closely planted coconut palms does reduce evaporation is readily admitted, but it is obviously futile if the additional palms producing the shade take up more water for their upkeep and growth than would be lost if the mulched soil were exposed to the sun ".

The damage that may accrue from the incidence of pests and diseases is also to some extent bound up with spacing. Under conditions of closer spacing, the chances of their quick spread are greater. For instance, damage to nuts from rats may be serious as they can find easy access from tree to tree due to the overlapping of leaves and easily elude the tree climbers in their attempts to locate and destroy them.

It must be borne in mind that the cost per unit of production and of unit area will be altogether less, the fewer the number of palms there are to produce the maximum possible yield.

Systems of planting. Four systems of planting, viz., square, triangular, oblong or rectangular and quincunx are mentioned (Ganarajah, 1954) of which the first two are the more common ones (Fig. **55**). In the square system, the palms are set at fixed equal distances at the corners of each square, the distance between palms in each row and the distance between adjacent rows being the same. In the triangular system, the palms are set at fixed distance at the corners of an equilateral triangle. In this system about 15 per cent more palms can be accommodated in an unit area as can be seen from the statement given below:

Table 29.—Number of palms per acre in relation to planting distance and system of planting

Planting distance	Number of palms per acre	
	Square system of planting	Triangular system of planting
6·7 m	90	104
7·0 ,, ...	82	94
7·3 ,, ...	76	87
7·6 ,, ...	70	80
8·0 ,, ...	64	74
8·3 ,, ...	60	69
8·6 ,, ...	56	64
8·9 ,, ...	52	60
9·2 ,, ...	48	56

In the quincunx system, the seedlings are planted in the centre of each square of old palms. This method is used only for replanting in old plantations where old trees will be removed as soon as the new seedlings are established. In the oblong or rectangular system, the rows cut at right angles to one another but the distance between the palms in the row is greater than that between the two rows. This is said to give a slightly higher stand than square planting and to allow more room for raising catch crops in the plantation. Abeywardana (1954) has given the formulae for calculating the number of palms that can be accommodated in an area for any planting distance both in the square and triangular systems of planting.

Size of pits. After peg marking the site, the next operation is digging of pits. The size of the seedling pits to be dug will depend upon several factors, such as the nature of the land, the type of soil, the depth of water table, etc. Generally speaking, the harder or heavier the soil, the larger should the pits be. For light soils 1 m × 1 m × 1 m pits are recommended (John, 1952; *Leaflet* No. 18, *Coconut Research Institute, Ceylon*). On hard laterite soils 1·3 m × 1·3 m × 1·3 m pits are necessary so that the hardened portion of the laterite would have been broken and removed. Cheyne (1951) has suggested a modified " Cruciform " planting hole for hard ground. The special feature of this planting hole is that from the sides of the ordinary one further excavations of smaller dimensions of ½ m × ½ m × ½ m extending outwards are made and this is claimed to facilitate easy spread of the roots of the young seedlings in the early stages of their development. In sandy soils, shallow pits of one-third to one-half metre in depth are adopted.

Depth of planting. Though there may be uniformity in the size of the seedling pits, the actual depth at which the seedlings are planted is found to vary. In India, the top of the nut when planted is 0·6 m to 0·75 m below ground level, while in Ceylon, the seedling is planted about 20 cm to 30 cm below ground level. In Malaya, the seedlings are planted so that the top of the nut is just above the level of the ground.

Surface planting is not advisable particularly where drought conditions are likely to prevail. Surface planting results in restricting the bole area and favours the formation of a shallow root system. Surface planted trees are reported to reach the stage of bearing early. This has not been confirmed by a field trial carried out at the Agricultural Research Station, Nileshwar-I (India) in the gravelly soil, where surface planting was under comparison with half, three-fourths and one metre deep planting. In the earlier stages, surface planted seedlings suffered more casualties than the others. In other respects such as vigour of growth, flowering time or yield there was no significant difference among the different depths of planting. In loamy soils also similar results were obtained.

Under conditions where water-logging is possible, the seedlings are planted actually on mounds made of soil. As the seedlings grow up, the intervening space is gradually filled up to form a continuous bund.

Digging of pits and planting. The seedling pits are usually dug two to three months in advance of transplanting time and allowed to weather. The surface soil is kept separate and the subsoil utilised in making a small bund all round to prevent rain water flowing into the pit. Husk or trash is then burnt in the pits once or twice to char the sides. This prevents termite attack. In hard laterite areas, a few handfuls of common salt are also put into the pits with a view to softening the laterite.

Just before transplanting the seedlings in the pits already dug for the purpose, the bottom of the pit is well dug up and a mixture of surface soil, sand and ash put in it to about 30 cm in depth. In Ceylon, the recommendation is to spread two layers of husks with their concave sides up, at the bottom, and then to fill the hole to within 15 cm to 20 cm of the surface with good top soil mixed with about 18 kg of wood ash. After the seedling pits are prepared as indicated, the seedlings are placed in a hole dug in the centre of the pit with the nut buried so that the top of the husk is just visible outside. The earth is well pressed down in order to keep the seedling firmly in position. If the season is windy, the seedlings may be given support by providing suitable props for a year or more till they strike roots and get established. The best method of propping seedlings is to provide three posts in a triangular fashion and tie cross-strips at two or three different heights, according to the height of the seedlings. Tarring the props would prevent termite attack and rotting and make them last longer.

Season of transplanting. The season of transplanting seedlings will vary from place to place depending upon the situation of the land and climatic conditions. Generally in most of the areas the best time for transplanting is at the commencement of the monsoon. On the West Coast of India and Ceylon, May to June and October to November are the usual planting seasons. In low-lying areas subject to

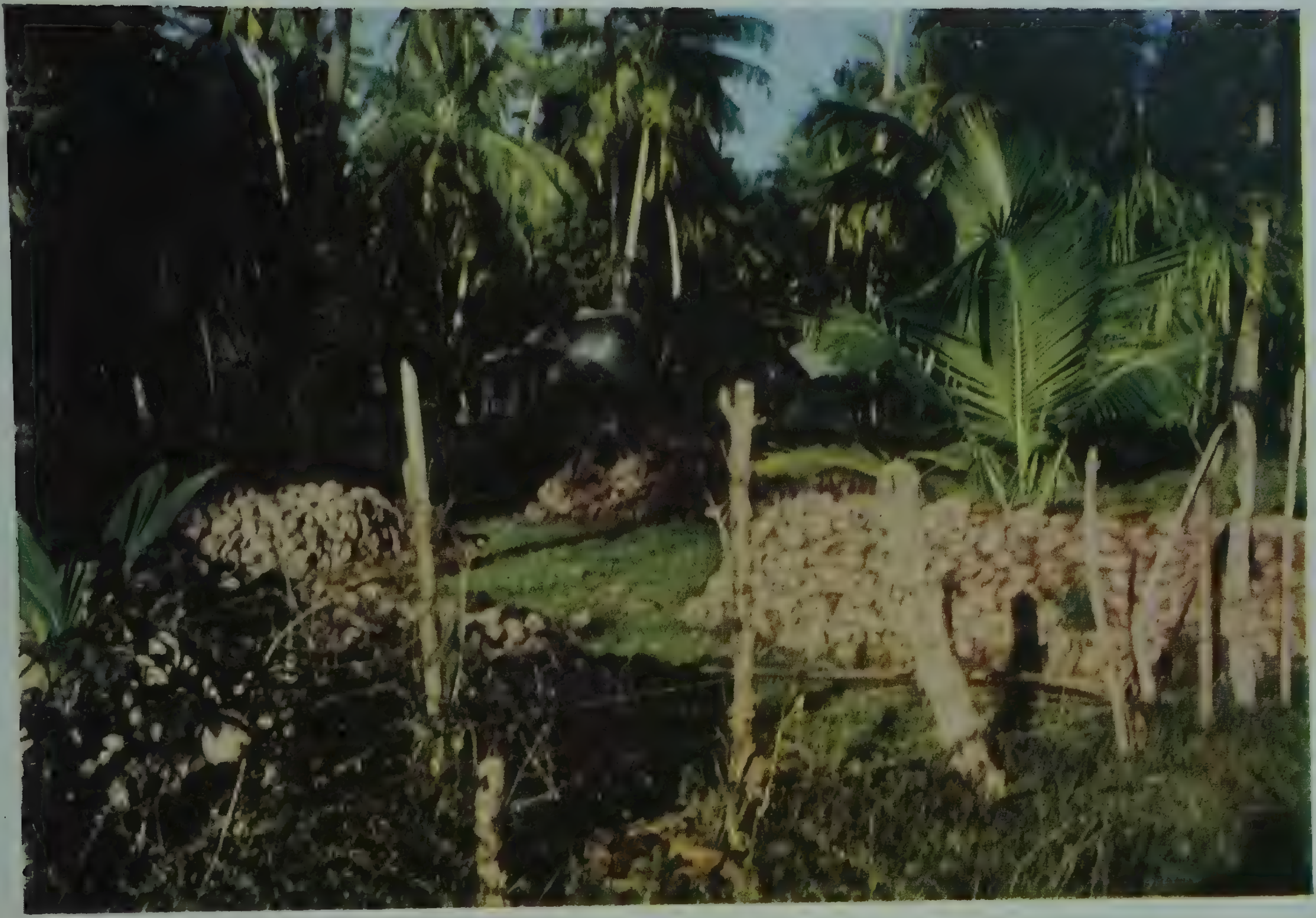
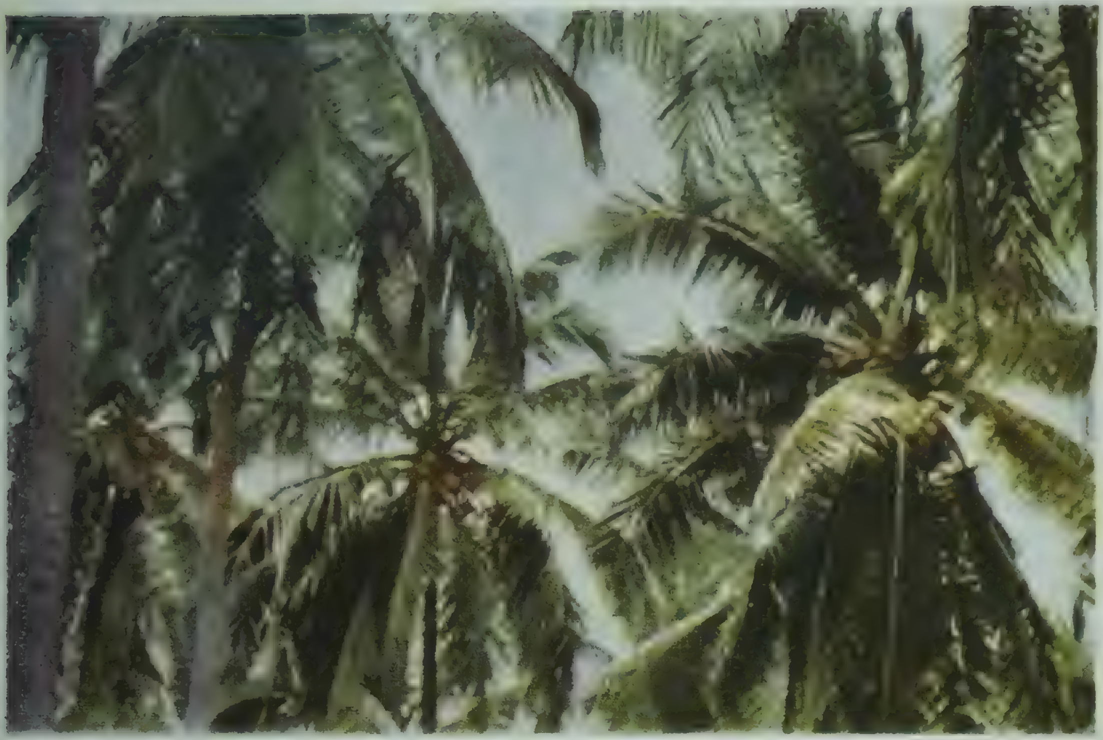
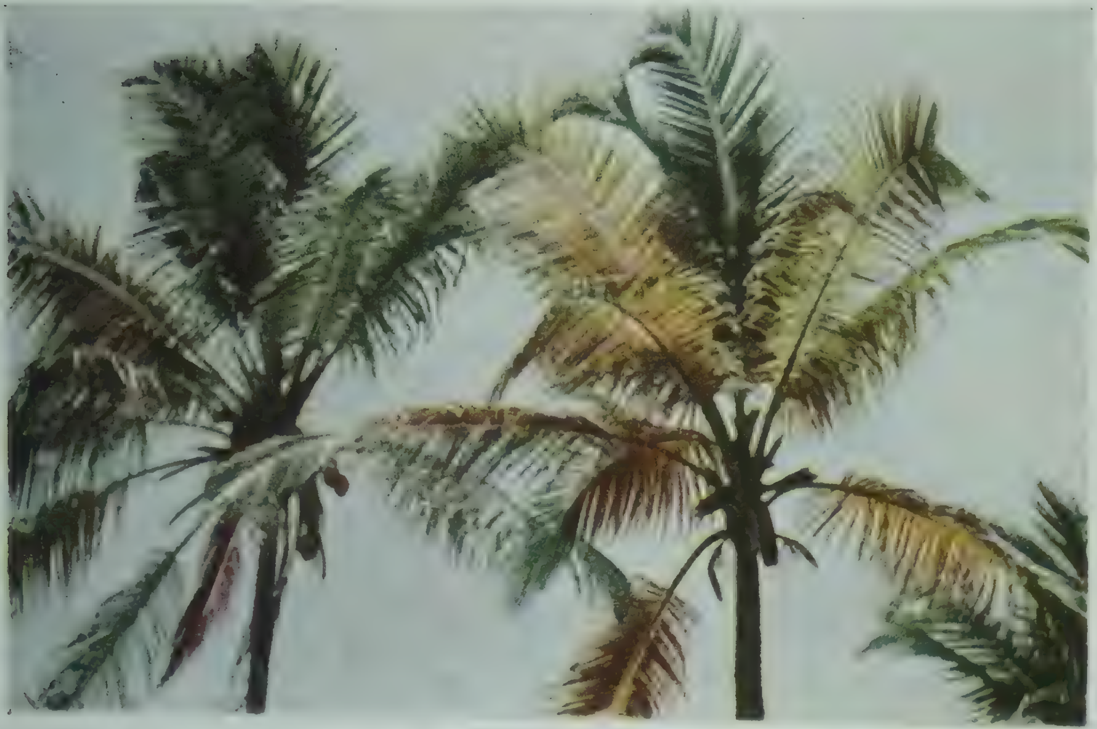


Fig. 59. Kottuwa (wall of husks)



Crowns of trees receiving potash – note healthy green leaves and heavy bearing bunches of nuts

Fig. 60. Importance of potash
(Courtesy "Potascheme", Bangalore, India)



Crowns of trees receiving " no potash " – in distinct contrast to trees in potash plot – showing bronzed leaflets on short fronds and very poor bearing

Fig. 61. Importance of potash
(Courtesy "Potascheme", Bangalore, India)

inundation during rainy season, planting is done before the commencement of the monsoon or after it is over. By planting in the appropriate season, it will be possible to ensure better establishment and save watering charges.

CARE OF YOUNG PLANTATIONS

The most critical time for the palm is during the early stages of its life, i.e., from the time of planting to the third or fourth year. It is only by giving careful attention during this period that the palms can be made to bear early and well. This aspect cannot be over-emphasised as instances where newly planted seedlings are allowed to be grazed by cattle, choked up with weed growth, killed by termites or drowned in mud and water do occur frequently.

Fencing. The newly planted seedlings should be protected from the depredation of cattle, till they grow big enough to be beyond their reach. Seedlings frequently grazed by cattle seldom make satisfactory growth. An indirect damage done by the cattle is that by trampling they harden and expose the ground around the young palms. If the seedlings are concentrated in one place, it is cheaper to fence round the entire block but where they are isolated or fencing of the entire area is not economic, protection has to be given to the individual seedlings. This can be done by erecting fencing with bamboo, raising mud or laterite enclosure (Fig. **57**) or providing wicker or bamboo cages. Very serviceable fencing at cheap cost can be made from the petioles and rachis (Fig. *58*) of the coconut leaves which would be available in any coconut plantation. In Ceylon, protection to individual seedlings is afforded by barbed wire or by putting up *Kottuwa* (a wall of husks) all round (Fig. *59*). Sprinkling of cow dung slurry on the leaves is effective, but may have to be repeated often particularly in rainy season (De Silva, 1953). Two patent chemicals tried as cattle repellents in Ceylon did not prove satisfactory (Liyanage, 1956).

Watering. The newly transplanted seedlings should be watered regularly in the absence of rains till they strike roots and get established. It is also necessary to continue watering the seedlings in the dry months for the first two or three years after transplanting, depending upon local conditions.

Shading. When the sun is very hot during summer months, the seedlings should be adequately shaded for the first one or two years. Provision of shade has been found to reduce casualties among the transplanted seedlings and also the frequency of watering. After the seedlings have established well and begun to grow satisfactorily, the shade can be dispensed with. Shading with coconut leaves round the seedling pits will provide adequate shade at a little cost (Fig. *56*). Light shading for the first two years is reported to check the ' grey blight ' of coconut seedlings.

Mulching. Mulching the area round the base of the palm before the onset of dry weather will keep the soil moist and prevent the ground from becoming hard. It will thus lessen the bad effects of drought conditions and promote better growth of the palms. During rainy seasons, it will also control weed growth. Satisfactory mulching can be done with materials such as coconut husk, leaves, coir dust, etc.

Cultivation and after-care. The seedling pits have to be cleaned periodically and kept free of weeds. During heavy monsoon rains, care should be taken to see that water does not stagnate in the pits continuously for long periods. The ring bunds raised around the seedling pits should be periodically repaired and kept in good condition. After the rains, any excess soil washed down into the pits and covering the growing portion of the seedlings should be removed. The seedling pits can be gradually filled up as the seedlings grow and form the stem.

The immediate surroundings of the newly planted seedlings should be clean-weeded and the surface soil kept in a friable condition by digging or forking the land to promote the development of roots. As the seedlings begin to develop, growth can be further improved by getting the entire garden ploughed or dug up with spade or hoe.

An alternate way of keeping down weeds is to establish a leguminous cover crop which will smother the weeds and also increase the fertility of the soil. A crop such as cowpea (*Vigna catjang*) which can also be used as a food crop will be more acceptable to the small coconut grower than *Calopogonium mucunoides* or *Centrosema pubescens* which are quite suitable for being grown in large estates. When cover crops are raised, it is essential that weeding around the young palms in ever widening circles is done. This will also prevent the creeping type of cover crops from climbing up the young palms and checking their growth.

Unrestricted growth of cover crops or weeds will retard the growth of young palms and delay the period of flowering. Cooke (1936) records a case in the Philippines where in a ' Cogon ' (*Imperata cylindrica*) infested land the palms took two years more to commence bearing than under ordinary conditions. The injurious effects of the same weed on coconut palms have also been observed in Malaya by Jagoe (1938), in British Solomon Islands by Pagden (1936) and in Ceylon by Rajapakse (1950). In Malaya, Belgrave and Lambourne (1934) found the cover crop to retard the growth of young palms growing in over drained soil.

Manuring. Proper manuring from the very beginning is necessary to give good start to the seedlings, unless the soil is virgin and of good inherent fertility. In Puerto Rico, McClelland (1931) got good response to manuring young palms. Cooke (1954) also states that proper manuring of seedlings will promote early bearing and high yields. However, Wilshaw (1941) did not get any benefit out of manuring young palms growing in the fertile and heavy coastal clay soils of Malaya.

The soil in which coconut is being raised in the majority of the coconut growing countries being poor, regular manuring from the very beginning would prove beneficial in the long run. The major manurial requirement of the seedling is potash though the response to its application will depend upon the extent to which it is already available in the soil. Next comes nitrogen. The normal requirement of the seedling for phosphoric acid is small, but where it is very deficient in soil, it can certainly prove a limiting factor. The remarkable response shown by young palms to added phosphoric acid at Ratmalagara Estate in Ceylon is an example. Potash deficiency or excess nitrogen is reported to make the young seedlings susceptible to leaf spot disease.

The general recommendation for the manuring of seedlings in India is the following :—

Year after transplanting	Quantity (kg) of manures per seedling per annum		
	Ammonium sulphate	Super-phosphate or bone-meal	Muriate of potash
I year	Nil	Nil	Nil
II and III years	0·25	0·25	0·25
III and IV years	0·50	0·25	0·50
V and VI years	1·00	0·50	0·75
VII years onwards	1·50	1·00	1·00

Ammonium sulphate can be substituted with groundnut cake or any other oil cake at the rate of 3 kg to 4 kg for every kg of ammonium sulphate. Similarly, muriate of potash can be substituted by good ash at 15 kg to 20 kg for every kg of muriate of potash.

In Ceylon the schedule of manuring of young palms is the following (*Leaflet* No. 8, *Coconut Research Institute, Ceylon*, 1955).

	Mixture A	*Mixture B*
2nd year	0·875 kg	1·125 kg
3rd year	1·25 kg	1·5 kg
4th year	1·5 kg	2·0 kg
5th and subsequent years until bearing ..	2·0 kg	2·5 kg

Mixture A

Sulphate of ammonia or calcium cynamide	2 parts
Saphos-phosphate	2 parts
Muriate of potash	3 parts
	7 parts

MIXTURE B

Sulphate of ammonia or calcium cynamide	1 part
Groundnut cake	3 parts
Saphos-phosphate	2 parts
Muriate of potash	3 parts
	9 parts

In the early stages till the stem is formed the manures may be applied close to the palm on the surface. As the palm grows, manures may be applied over a larger area. The application of green leaves or compost is to be avoided in the early stages, in areas where termite attack is present, as the damage due to it may increase.

Protection from pests and diseases. The young coconut palms are susceptible to attack from various pests and diseases. Frequent inspection of every plant may therefore be done and control measures taken promptly. Termites, rhinoceros beetle and the coconut caterpillar are the more important pests in India. Control measures against these are dealt with in Chapter XIV.

Shoot-rot and bud-rot diseases are also seen to attack the seedlings. Prompt measures taken in the initial stages alone will help to save the seedlings and hence early detection is very important. The way to deal with these diseases is indicated in Chapter XII.

Filling up of gaps. Provided all precautionary measures are taken, there should normally be no casualties among the transplanted seedlings. If however they do occur, they should be promptly replaced with good seedlings preferably of the same age. Seedlings showing continued unhealthy and stunted growth may also be replaced. For this purpose some surplus seedlings should be kept in reserve in the original nursery.

CARE OF ADULT PLANTATIONS

The young palms brought up according to the steps outlined above will begin to flower in about five to six years after transplanting. With the onset of the productive phase, the demands of the palm for plant nutrients from the soil will increase and soil management practices should be brought into force to provide optimum conditions for the palms to give of their best for the full bearing period. Regular and systematic manuring and control of the pests and diseases should receive sustained attention. Any neglect in this regard will have an adverse effect on the growth and yield of the crop.

Cooke (1932*a*) has given an example from Ceylon to show what improvement in yield can be brought about by systematic manuring and cultivation. In an estate while a regularly cultivated and manured block yielded on an average ninety nuts per tree per year, the unmanured but cultivated block gave only an average yield of thirty nuts per tree. The increase in yield reported to have been obtained over a series of years is given below : —

Increase in yield due to manuring

Year	*Nuts per acre*	*Year*	*Nuts per acre*
1920 ..	3,160	1926 ..	3,990
1921 ..	3,450	1927 ..	3,750
1922 ..	3,540	1928 ..	3,840
1923 ..	3,310	1929 ..	3,890
1924 ..	3,710	1930 ..	3,950
1925 ..	3,569		

Similar results have been obtained in India also. The yield from a regularly cultivated and manured plot at the Central Coconut Research Station, Kasaragod, averaged over a long period of 20 years was sixty-four nuts per year as against a very poor yield of ten nuts obtained from a completely neglected plot. Any number of similar examples can be cited but the above will suffice to show that only under good care and management can sustained high yields be obtained. Though the benefit of good management is beyond doubt, for obvious reasons, the gardens of small holders with a few exceptions remain practically neglected with the result that they yield only very poor crops.

Manuring

The materials commonly used in India as manure for the coconut are cattle manure, ash, green leaves, lime, fish guano, prawn dust, and oil cakes of groundnut, *marotti* (*Hydnocarpus wightiana*), etc. In certain areas sheep-penning is also practised. In Ceylon, tethering a pair of cattle for seven to ten nights, or application of dry cattle manure collected from grazing areas are the methods of manuring adopted by small growers. In the Philippines, manuring is not reported to be practised to any great extent. The position does not appear to be in any way better in the other coconut growing countries either. However, of late, the use of fertilisers such as ammonium sulphate, super-phosphate, muriate of potash, saphosphosphate, etc., is becoming increasingly popular among progressive growers.

As a result of extensive investigations carried out on the manuring of coconut palms particularly in India and Ceylon, schedules of manuring have been drawn up for the guidance of the growers. The following are some of the manurial combinations recommended for different soil types on the basis that adult palms require about 0·25 kg to 0·50 kg of nitrogen, 0·1 kg to 0·25 kg of phosphoric acid and 0·375 kg to 0·75 kg of potash per tree per year (John, 1952).

Mixtures for sandy soils

Mixture 1.	Cattle manure or compost	50 kg
	Wood ash	10 kg to 20 kg
Mixture 2.	Fish guano	7·5 kg
	Muriate of potash or potassium sulphate	1·0 kg
Mixture 3.	Prawn dust	7·5 kg
	Muriate of potash or potassium sulphate	1·0 kg
Mixture 4.	Groundnut oil cake	7·5 kg
	Wood ash	10 kg to 20 kg
	Bone-meal	1·0 kg

Mixtures for soils not deficient in organic matter

Mixture 1.	Ammonium sulphate	1·5 kg to 2 kg
	Muriate of potash or potassium sulphate	1 kg
	Bone-meal	1 kg
Mixture 2.	Groundnut or other oil cake	7·5 kg to 10 kg
	Ash	10 kg to 20 kg
	Bone-meal	1 kg

The above mixtures are recommended to be applied over a basal dressing of green leaves at 25 kg to 50 kg or cattle manure or compost at 25 kg per tree per year. Instead of green leaves, green manure crops can be grown *in situ* and incorporated. This aspect of green manuring has been dealt with in detail in Chapter X.

The manurial chart drawn up for bearing palms growing on different types of soil in Ceylon is as follows :—

Table 30.—Manurial chart for bearing coconut palms on different types of soil

NPK requirements	(kg of nutrient per palm once every two years)									
	White cinnamon sands and coarse marine sands		Loams and sandy loams		Clay soils		Laterite		Lateritic gravel	
	A	B	A	B	A	B	A	B	A	B
Nitrogen	0·35	0·3	0·3	0·25	0·3	0·25	0·35	0·3	0·3	0·25
Phosphoric acid	0·45	0·40	0·4	0·3	0·4	0·3	0·45	0·4	0·45	0·4
Potash	0·75	0·62	0·62	0·5	0·5	0·4	0·75	0·62	0·75	0·62

A : Estates which have not been manured for a long period.
B : Estates which have been regularly manured.

The quantity of fertilisers to be used to supply the above-mentioned amounts of nitrogen (ammonium sulphate, calcium cynamide, groundnut cake or sediment poonac), phosphoric acid (saphos-phosphate, bone-meal) and potash (muriate of potash and kainite) has also been indicated. Some more formulae for other manure mixtures for the coconut are given by Salgado (1946).

The proper time for the application of manures is when there is sufficient moisture in the soil. Manuring should not be done when there is heavy rain as manures are likely to be lost by surface wash or through leaching. Application of manures during dry periods or when there is not sufficient moisture in the soil is not only not helpful but positively harmful.

The manures may be applied in basins dug around the base of the trees in gardens where the palms stand irregularly or where the crop is grown interplanted with other kinds of trees. In gardens where coconut alone is raised and spacing is not too wide, manures can also be applied broadcast and covered up by digging or ploughing.

Selection of fertilisers

A good knowledge of the different kinds of fertilisers and other locally available materials of manurial value will enable manuring to be done both effectively and cheaply. The materials of manurial value available in Ceylon have been mentioned in *Leaflet* No. 9 (1954) *of the Coconut Research Institute, Ceylon.* The usefulness of the manures depends upon the manurial constituents they contain and these will show considerable variation depending upon the care and attention bestowed in their preparation, storage and application. This is of particular importance in respect of manures such as farmyard manure, wood ash, etc., which can be valueless if they are not prepared or stored properly. The composition of a large number of fertilisers and other materials of manurial value which can be used as possible sources of nitrogen, phosphoric acid and potash is given by John and Verghese (1951).

When a range of manures containing the same nutrients is available, a proper selection can be made by valuing them on the basis of the manurial ingredients. The basis is usually the unit value, i.e., the cost per ton divided by the percentage of the manurial ingredient. Such evaluation will enable the grower to choose the most economic manures to supply the different manurial ingredients in required quantities.

The nature, condition and fertility status of the soils also require to be given due consideration when manures are selected and their dosages decided. For fertile soils, lesser quantities would suffice. In sandy soils organic forms of fertilisers will be preferred to inorganics. In lateritic soils which have a high fixing capacity for water soluble phosphate, bone-meal may be preferred to super-phosphate. Salgado (1950) has discussed the manurial needs of all the important coconut soils of Ceylon.

Application of manure mixtures

Since the process of application of manures to coconut gardens, namely spreading and covering is a costly operation, it is easier and more economical to mix the different manures instead of applying them separately. In mixing, care should be taken to see that the manures are compatible. Ammonium sulphate or other fertilisers containing ammonia should not be mixed with wood ash or lime since chemical action will set in and nitrogen will be lost in the form of ammonia. Croucher and Martinez (1934) found that a mixture containing two parts of coconut ash and one part of sulphate of ammonia lost in five days 50 per cent of ammonia when spread over dry soil and 80 per cent when the soil is wet. The loss was reduced when the manures were incorporated into the soil immediately after spreading or the ash used was completely dry and the mixture stored in a dry place. As a safe precaution, ammonium sulphate may be applied at least a fortnight before or after the application of ash. Salgado (1939) has shown that loss of nitrogen from ammonium sulphate can also occur if it is mixed with ground mineral phosphates. Potash fertilisers which absorb moisture and cake up should not be stored mixed with ammonium sulphate or super-phosphate. There is no harm in mixing them just at the time of application.

Cultivation

Besides manuring, proper inter-cultivation of the coconut gardens is also necessary. Inter-cultivation by itself has been proved to increase the yields substantially, under the conditions obtaining on the West Coast of India. Inter-cultivation may be done by ploughing the garden or by digging once or twice in the year. The object of inter-cultivation is primarily to remove weeds and create soil mulch. Sometimes basins are also opened around the base of the trees. In the sandy soil areas of Travancore-Cochin (India), piling the soil of the entire garden into small heaps towards the end of the south-west monsoon and levelling them up again after two months is widely adopted with beneficial results.

The following is the cultural and manurial schedule drawn up for the coconut gardens on the West Coast of India. For other tracts this may have to be modified to suit local conditions of soil and rainfall.

March to April

During this period one ploughing with an iron plough to prepare the land to receive the summer showers may be given.

May to June

After a soaking rain is received, green manure crop such as cowpea, wild sunn-hemp (*Crotalaria striata*) or sunn-hemp (*Crotalaria juncea*) may be sown at the proper seed rate and covered by working a light plough. It would be desirable to give a basal dressing of ash at twenty pounds or cattle manure at hundred pounds per tree, just before the sowing of the green manure crop. If bone-meal or super-phosphate is proposed to be applied, it may be incorporated into the soil before the sowing of the green manure crop.

August to September

The green manure crop may be cut down and ploughed into the soil with a suitable iron plough. Ammonium sulphate and potassium sulphate or muriate of potash may be applied in basins or may be broadcast and ploughed in, according to local practice, along with the green manure crop at the first or second round of ploughing.

October

Bunds washed off during rains may be rectified.

December

To create soil mulch, a cultivator may be worked in the gardens.

Removal of unproductive palms and thinning

A few palms showing stunted growth or unproductive nature are often met with even in well-managed gardens raised with quality planting material. These should be removed and replaced as early as possible. The proportion of unthrifty palms is usually large in the gardens of small holders because of close planting and insufficient care. In such cases thinning is to be done until the desired spacing is reached. Unproductive and senile palms should be first removed followed by further thinning wherever necessary. Pieris (1945) has given data regarding the approximate number of palms and the fraction of stand that has to be removed in order to bring about desired spacing. He has also furnished diagrams to illustrate satisfactory methods of removing one-third and one-fourth of the stand.

Control of pests and diseases

The adult palms are found to be attacked by a number of pests of major and minor importance and all these are capable of causing considerable damage, resulting in reduced yields. The need to take prompt control measures against them cannot be over-emphasized. Information on these aspects is given in Chapters XII and XIV.

Irrigation

Soil moisture is often the greatest limiting factor for the successful growth of the coconut. Where rainfall is meagre and ill-distributed or where long periods of dry spells prevail, adequate soil moisture should be ensured by irrigation to obtain satisfactory growth and yields. Failure to provide irrigation even for short periods would have disastrous consequences, under such conditions.

On the West Coast of India, though the annual rainfall is very high, drought conditions occur for four to five months in the year and this is found to affect the growth and productivity of the palms, particularly in sandy soil where the moisture content in summer goes down to as low as 0·1 per cent. In such cases, where facilities exist, irrigation during summer months can be done with considerable benefit to the trees. Phenomenal increase in yields is reported to have been obtained in Ceylon through irrigation. Wardlaw and Mason (1936) have reported as having obtained considerable increase in yield in Malaya by proper irrigation and drainage control.

In the coastal sandy areas on the West Coast of India and also in parts of Ceylon, sea water is found to be utilised for irrigating coconut palms without any apparent ill effects. At the Central Coconut Research Station, Kasaragod (India), the use of sea water for irrigating coconut palms growing in littoral sandy soil during summer for a period of six years not only did not give any evidence of bad effect, but actually improved the appearance and productiveness of the palms. In heavy soils, the use of sea water is reported to give bad effects.

There is a widespread belief among growers that gardens which are regularly irrigated, deteriorate rapidly if irrigation is discontinued, even for a short period. No definite experimental proof is available to substantiate or disprove this contention. It is quite possible that as a result of irrigation, the root system expands and the tree is stimulated to produce more and larger leaves resulting in increased demand for water. If this need is not satisfied, the trees naturally are bound to suffer.

HARVEST AND STORAGE OF NUTS

A female flower of the coconut takes about twelve months to develop into a mature nut. Since a regular bearing palm produces an inflorescence in every leaf axil at intervals of about a month, a bunch will become ready for harvest every month, right through the year. Though this is the case, harvest being a costly operation, is not ordinarily done every month except in heavy-yielding gardens. The number of harvests done vary in the different coconut areas in India; in the West Coast, six to eight times a year; in Tanjore, Godavari and Bombay, six times; in Orissa four times and in Assam once or twice a year. In Ceylon and the Philippines, the harvest is done six times a year, at bimonthly intervals.

Harvesting of nuts before they are fully mature, *i.e.*, when the nuts are eleven, ten or even nine months old is practised when the green husks are required for retting purposes. In Bengal and Bombay, tender nuts are reported to be harvested four to five times in a year.

The effect of harvesting nuts before they are fully mature on the quantity and quality of copra, oil and fibre has been studied (John *et al.*, 1948). Copra and oil content per nut are at a maximum in the fully mature (twelve months old) nut. By harvesting less mature nuts, copra is lost to the extent of 6 per cent in 11-month-old nuts, 16 per cent in 10-month-old nuts and 33 per cent in 9-month-old nuts. The loss in the quantity of oil also comes almost to the same extent. Besides, the copra and oil suffer in quality also. In the outturn and quality of fibre from the husks there was not much difference between 10 and 11-month-old nuts. The fibre from fully mature nuts was definitely inferior being brittle and of dark colour. The relevant data are summarised below:

Calculated yield of copra, oil and fibre in kg from 1,000 nuts in relation to maturity of nuts

	Maturity of nuts (months)			
	12	*11*	*10*	*9*
1. Quantity of copra	162	152	135	108
2. Quantity of oil	111	106	94	74
3. Quantity of coir fibre	79	78	75	79

It was concluded from the above studies that the practice of harvesting nuts which are less than eleven months old is wasteful and should be discouraged.

Method of harvest. In India harvesting of coconuts is commonly done by skilled labourers who climb the trees with the help of rope rings held tight around the feet or ankle or by using a ladder. In Ceylon, harvesting is done from the ground with the help of a knife attached to a long bamboo pole. In Malaya and Thailand trained monkeys are reported to be made use of for harvesting nuts.

In countries where there is a shortage of skilled labour, for example, parts of Africa, Pacific Islands, such as Samoa and British Guiana, etc., the nuts are not harvested but allowed to fall of their own accord and the fallen nuts are collected from the ground at intervals. In this case the risk of loss of nuts through theft is very high. Simpson (1941) has concluded from his studies in Malaya that by allowing the nuts to fall naturally a loss of copra to the extent of seven to eight per cent is sustained arising from the effects of germination. Studies carried out in Ceylon, (Rodrigo, 1938) appear to have shown that in fallen nuts copra content is more, but oil content is less.

Storage. In India, the harvested nuts, particularly those that are to be converted into copra are stored for some time in shade in specially constructed coconut stores. If, however, the husks are required for retting, the nuts are husked soon after harvest. In Ceylon, the nuts are kept heaped in the open garden till they are disposed off. A few nuts in these heaps are often found to germinate or rot.

From the point of view of making copra, a limited period of storage of unhusked nuts is found to be beneficial in the following ways.

(1) Husking is made easier as fresh green nuts are more difficult to husk.

(2) Shelling is cleaner and easier since the kernel detaches quicker from the shell.

(3) The resulting shells are dry, hard and burn well without smoke.

Cooke (1932*b*) has shown that storage is beneficial only if the nuts are not fully ripe at the time of harvest and that good quality of copra can be prepared from green nuts themselves immediately after harvest if the nuts are picked in the fully ripe condition.

UNDERPLANTING AND REPLANTING

In the life of a coconut plantation there reaches a stage when the yields of trees begin to decline due to the onset of senility. It is uneconomic to maintain such plantations any more as they cannot respond to manuring or cultivation. The age at which a palm begins to decline in yield depends upon a number of factors such as variety, soil and climatic conditions, care and attention bestowed, etc. Other conditions being the same, the maximum life of the dwarf variety is considerably shorter than the tall. In good soil with proper attention the tall variety palms may continue to be in prime condition even after the 80th year. On the other hand, prolonged neglect may accelerate the decline of productivity and bring about the unproductive stage much earlier. In general, it can be assumed that bearing would be on the decline after the 60th year.

Underplanting should be taken up when a definite tendency for the yields to decline, in spite of care and attention, is discernible. This should be so timed that the production of the garden is not unduly affected, during the change over. That this is possible of achievement in practice has been demonstrated from the results obtained in Ceylon (Cooke, 1954). If underplanting is done too early, the newly planted palms will suffer from root competition and shade effects of the old palms. The older palms may have also to compete later with young palms. If underplanting is delayed very much, the older palms will cease to bear and there will not be any production from the garden for a number of years till the newly planted seedlings reach the bearing stage.

The problems arising in underplanting have been discussed by Fernando (1950) and Rodrigo *et al.* (1952). If underplanting is to prove a success, two aspects need particular attention. One is that the old palms should not be left standing for too long. The entire stand should be removed if necessary in stages, so that the garden will be completely free of old palms in about six years after underplanting. A field trial has been initiated in Ceylon in 1950 to study different systems of replanting with the object of finding out an economic method whereby the bearing age of the young palms is not unduly delayed and its potential yield not permanently retarded due to the presence of old palms. The treatments under comparison are :—

(*a*) New clearing (planting after the complete removal of old stand of palms) ;

(*b*) Gradual thinning (underplanting and removing the old stand gradually, 20 per cent of the old stand being removed in the first year and 10 per cent every subsequent year) ; and

(*c*) No thinning (underplanting and the removal of old palms when the young palms reach the flowering stage).

The results of the studies on the growth of seedlings are reported to be in favour of new clearing, gradual thinning and no thinning in the order given. Final appraisal has to wait till the palms begin to bear normally.

The second factor to be given due consideration is the proper manuring of the underplanted seedlings. Since the soil would have been exhausted by the original plantation, seedlings should be adequately manured. Salgado (1951) says that underplanting without manuring is a sheer waste of money. Experiments at Letchemy Estate, Ceylon, have shown that proper manuring will bring the underplanted palms to the flowering stage earlier and also make them bear well.

One precaution to be taken in underplanting is that the seedling pits should, as far as possible, be dug farther away from the existing trees or the stumps of old trees. If it is proposed to plant the seedling at the site of an old palm, the stump of the old tree should be dug out and removed along with the matting of roots and burnt in the pits. If these steps are not taken, the growth of the freshly planted seedlings is likely to be adversely affected.

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CHAPTER IX

SOIL CONDITIONS IN RELATION TO THE NUTRITIVE ASPECTS

The paramount importance of the need in an available form of the different plant nutrient factors in the soil for the optimum growth and productivity of the coconut palm has been emphasised by several workers. A general idea of the nutritional requirements of the palm can be had by determining the essential elements which are removed by it from the soil. The food factors may often be present in the soil and still be not available to the plant. The soil may appear from results of chemical analysis to be deficient in a particular essential element, but still the palm may apparently thrive well and also often yield well. These limitations of our knowledge on plant needs and the ability of the soil to supply them, point to the need for systematic field experiments to be carried out. The coconut is a perennial palm and on account of the difficulties of carrying out pot culture experiments on its nutrient aspects, unlike annual plants like the tobacco, the tomato, or the potato, it takes a very long time to obtain experimental results of its nutrient requirements. Great difficulty in handling this crop in experimental procedure has been responsible for the inadequate knowledge about its nutritional requirements, and the conditions imparting health or disease resistance.

THE EFFECT OF THE NUTRIENTS

Nitrogen

The supply of nitrogen which is a constituent of plant cells as well as chlorophyll, the green colouring matter of leaves, is of great importance for the rapid development and growth of the trees. Nitrogen deficiency is reflected in deficient leaf formation as well as in restricted growth. Nitrogen promotes the development of the vegetative parts of the plant especially the leaves and shoots. The complete effects of nitrogen in plant metabolism could be achieved only if phosphoric acid and potash also are provided.

Phosphoric acid

Phosphorus is found especially in leaves and seeds as well as in all parts of the plants where vigorous cell division is taking place. Phosphorus deficiency results in deficient root development and delayed ripening of the fruit. Characteristic discolouration often occurs on the leaves where phosphorus is in short supply. Excessive phosphorus dressings do not act unfavourably on plant growth because part of the phosphate gets fixed in the soil in forms not readily soluble. Potash and phosphoric acid act jointly in many of their functions. The two together help the formation of sugar, starch and fats as well as in protein synthesis. They particularly promote flowering, fruit setting and root development, speed up ripening and increase resistance to certain diseases and pests. Potassium in the presence of phosphorus improves the quality characteristics of the produce, such as flavour, keeping quality, fruit colour, grain weight and size.

Potash

Potash has its important specific functions apart from those which it jointly performs in association with phosphorus. It regulates the water economy of the plant and so is indispensable for the rational utilisation of limited water supplies for the production of the highest possible yields. It enables the plant to withstand drought. Potash is known to help root development, enabling the palm to take up more nutrients from the soil. Since potash is particularly necessary for the formation of sugar, fat, and fibrous material, the coconut palm may be expected to have a high requirement of potash. Adequate potash metabolism enables the plant to be highly disease-resistant. Potash increases yield and improves the quality of plant products. It regulates protoplasmic swelling and streaming in plant cells and so directly influences enzyme action in them. The movement of iron in the plant is facilitated by potassium and hence it has an indirect effect on the formation of chlorophyll. It has been said that a concentration of potassium occurs generally in the growing parts of the plant where life and growth processes are intensive. Sampson (1923) has estimated that 41·5 per cent of the ash in the leaflet of a one to two-year-old seedling is potash. This is 29·4 per cent in the two to three-year-old plants. In the green leaf of the young tree which has not yet reached the bearing stage, there is 4·5 per cent potash in the leaf stalk and 18 per cent in the leaflet. In the leaf stalk of the green leaf of the bearing tree, there is 5 per cent and in the leaflets there is 13 per cent potash. The ash of the fully developed coconut tree contains 18 per cent potash while in the old leaf its percentage is 13·75. It may thus be seen that the demands of potash are rather heavy in coconuts and the importance of its role in the nutrition and physiology of the palms cannot be over-emphasised. On account of these facts it is certain that potash must be having very vital functions in the coconut palm. Experiments conducted in Ceylon (Salgado, 1952 *b*) have shown that potash has an effect on the earliness of bearing of the palms. Palms receiving potash were observed to begin bearing fruit in the fifth year of planting while palms receiving no fertiliser took eight years to bear. It was also seen that nitrogen caused an 8 per cent increase in copra yield while potash gave an increase of 25 to 39 per cent (Salgado, 1947 *b*). It would seem that the nitrogen/potassium ratio has some influence in the earliness of bearing as well as in copra yield. The absorption of potash is interfered with by an excess of nitrogen and phosphoric acid, particularly the former, showing the need for a balanced application of nutrients for optimum effect. Salgado (1953) found that potash deficiency leads to chlorosis and leaf scorch and the development of poor crown with short fronds. Results obtained from Ceylon do not seem to support the view that there is increased oil content of copra observed as a result of optimum potash function in the palm. Menon and Nair (1952) made comparative studies with copra and oil from healthy and diseased trees, but did not observe any significant difference in the oil percentage. The results of a few determinations are given below.

Table 31.—Moisture, ash and oil content of copra from healthy trees and trees in the different stages of disease

Harvest Batch No.	Tree No. and condition	Moisture per cent	Ash per cent	Oil per cent
I	203 A	3·5	1·97	66·63
	25 M	3·5	2·39	69·33
	3 E	3·5	1·76	72·20
	13 H	3·5	1·56	72·80
II	203 A	4·5	1·78	61·50
	25 M	4·7	2·98	69·50
	3 E	5·0	1·91	69·88
	13 H	5·2	1·58	63·59
III	203 A	9·7	2·22	68·44
	25 M	5·2	2·43	70·00
	3 E	6·0	1·92	45·00
	13 H	5·2	2·11	68·80
IV	203 A	3·2	1·86	82·61
	25 M	2·2	1·33	80·62
	3 E	2·6	1·85	72·90
	13 H	2·4	2·50	68·70
V	203 A	2·1	1·84	55·21
	25 M	2·5	2·05	75·00
	3 E	2·5	1·85	78·83
	13 H	1·8	1·73	61·12
VI	203 A	2·6	2·54	70·70
	25 M	3·2	1·86	73·40
	3 E	2·5	1·64	81·02
	13 H	3·0	1·55	81·20

Note : A stands for advanced stage of disease.
M stands for middle stage of disease.
E stands for early stage of disease.
H stands for healthy.

However, the N P K manurial plots gave in general copra samples with higher contents of oil, N, P, K, Ca and Mg than from the no manure or merely green manure treated plots as is seen in the following tables.

Table 32.—Oil content of copra samples from trees subjected to different manurial treatments

Treatments	Oil per cent
Control (No manure)	62·71
Green manure	56·77
N P K + lime	64·30

Table 33.—Results of analysis of copra samples from trees under different manurial treatments

Treatment	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent
1943					
Control	2·138	0·759	0·378	0·053	0·025
Green manure	2·265	0·773	0·275	0·051	0·033
N P K	2·449	0·804	0·669	0·033	0·041
N P K + lime	2·253	0·782	0·401	0·043	0·040
1944					
Control	3·250	0·918	0·989	0·122	0·086
Green manure	3·090	0·927	0·872	0·126	0·123
N P K	3·370	0·880	1·210	0·139	0·052
N P K + lime	3·340	0·815	0·734	0·136	0·063

The results of the determination of the physical and chemical constants of the oil presented in the following tables showed that the effect of different manurial treatments had no apparent influence on the quality of the oil samples.

Table 34.—Oil analysis

Treatment	Sp. Gr.	Moisture per cent	Iodine value	Saponification value	Soluble acids per cent	Free acid value	Reichert Meissal value	Polenske value	Krischner value	Insoluble acids per cent
1941										
Control	0·9226	0·117	8·9	256·8	3·0	1·26	1·61	0·86	0·97	79·2
Green manure	0·9249	0·118	10·2	253·6	2·4	1·13	1·24	0·88	0·89	74·7
N P K	0·9248	0·112	7·7	251·6	2·2	2·27	2·62	3·81	1·38	72·8
N P K + lime	0·9227	0·176	9·8	256·6	3·1	0·91	1·36	1·50	0·77	77·4
1942										
Control	0·9301	0·113	7·9	254·2	2·4	1·99	1·59	1·25	1·24	79·5
Green manure	0·9289	0·110	9·2	253·6	2·1	1·69	1·48	1·29	1·16	74·3
N P K	0·9273	0·105	8·1	252·8	2·0	1·99	1·50	1·56	1·30	78·7
N P K + lime	0·9295	0·115	8·8	253·5	2·5	1·98	1·50	1·26	1·21	78·1
1943										
Control	0·9367	0·290	6·80	235·9	2·6	3·03	1·30	0·53	1·50	69·2
Green manure	0·9406	0·240	7·03	242·2	3·1	2·06	1·28	0·34	1·56	72·7
N P K	0·9455	0·215	8·30	238·3	2·5	2·73	1·24	0·39	1·73	70·7
N P K + lime	0·9408	0·238	6·88	231·4	2·0	2·21	1·25	0·50	1·76	71·5

Potash in relation to disease resistance

This aspect has received some attention in Chapter XIII. The beneficial effect of potash on the water economy and consequently on its resistance to drought effects has been emphasised in a report by Menon *et al.* (1950). Further, the leaves of the palms which are insufficiently supplied with potash are very susceptible to the attack by *Pestalotia palmarum.* Patel and Nair (1936) have observed that potash can reduce the incidence of shoot-rot attack and this has been attributed to the potash moiety of the nutrients which increases the resistance of the protoplasm to pathogenic organisms. Bain (1937) has reported that complete manuring is of service in combating the leaf disease of the coconut palm. This effect may be due to the correction of lack of balance in the supply of nutrients to the attacked plants. The effect of potash on disease resistance is probably to be found in the more rational absorption of water accompanied by a depression of an excessive transpiration by the palm. Potash deficiency is marked by unsatisfactory development especially of leaves. The palms remain small with thin trunks. Tip scorching of leaves has been well known to be a nutrient deficiency symptom which appears to be corrected by potash manuring (Figs. *60* & *61*). In order to illustrate the potash movements in the palm, Dwyer (1937) quotes Sampson's figures in the following table. The analysis of the potash content of the different parts of a coconut palm six to seven-year-old, not yet bearing, is compared with that of a bearing palm.

Table 35.—Potash content of the different parts of a young palm and a bearing palm

Percentage of K$_2$O in	Root	Stem	Stipules	Petioles	Leaflets
A. Young palm ..	0·14	0·50	0·051	Average .. .. 0·74 Tender .. .. 1·78 Old .. .. 0·12	Average .. .. 1·08 Tender .. .. 2·01 Old .. .. .. 0·55
B. Bearing palm ..	0·29	0·21	0·034	Average .. .. 0·26	Average .. .. 0·56
A. Young palm ..	3·33	10·89	2·68	Old .. .. 3·92 Green .. .. 4·24 Tender .. .. 34·6	Old .. .. .. 13·75 Green .. .. 18·13 Tender .. .. 40·94
B. Bearing palm ..	8·27	3·91	3·50	Average .. .. 4·17	Average .. .. 13·08

In comparing analysis of inflorescences about to open with a similar inflorescence after the kernel is formed, it is found that there is more than double the quantity of potash in all parts of the young inflorescence than the older one. The percentage of potash in the inflorescence (spathe about to open) is, on a ' barren ' palm, 15·8 per cent compared with 20·46 per cent in a normal bearing palm. Child (1950) has found that omission of potassium led in course of time to yellowing of foliage and incidence of attack of the leaf fungus *Pestalotia.*

All these points make it abundantly clear that potash is a nutrient factor intimately associated with the healthy and optimum growth and productivity of the coconut palm.

The micro-nutrient aspects

Due to the fact that complex materials supplying the primary elements of plant growth, nitrogen, phosphorus and potassium and the secondary elements calcium, sulphur and magnesium, were commonly used to prepare fertiliser mixtures, it was not evident for a considerably long time whether the secondary group was actually required or not for plant growth. The trend in recent years in the use of fertiliser salts of comparatively high purity has focussed attention on requirements of more nutrient elements. While primary and secondary groups are frequently in short supply in the different agricultural soils, the micro-nutrient elements have been assuming an important position in plant nutrition and in soil deficiency factors. Thus, a group of elements including boron, copper, iron, manganese, molybdenum and zinc are now receiving well deserved attention. It appears logical to assume that other elements may probably be added to this list as we gain additional knowledge of plant requirements under field conditions. The specific effects of each essential element necessary for plant growth furnish a working approach to the problem. Since the effects are mainly growth phenomena, their distinctive influence on plant development produced by a deficiency of any one of the elements essential for metabolism may be modified to a certain extent by other conditions controlling growth. Environmental conditions may modify rate of growth, and therefore, the rate at which the medium must supply necessary elements as well as the total quantities of these elements required. However, the characteristic symptoms due to a deficiency of an element will be found to remain essentially the same.

A shortage of one of the micro-nutrient elements necessary for plant growth was one of the first to emphasise a typical disease symptom as due to a deficiency. Iron shortage results in chlorosis. Chlorosis and iron deficiency have since become synonymous terms. Iron deficiency is often induced by excess of manganese in soils. Iron chlorosis may be induced by soil reaction some times spoken of as lime-induced. While manganese is well known to be essential for many plants, acid soils containing an excessive quantity of manganese exert manganese toxicity effects. Thus it is seen that the effects are very complex, and influenced by different soil conditions and availability of the nutrient in the soil. The specific and varied function of each of these elements for normal plant growth is not well understood. It has been shown for example that magnesium is necessary for chlorophyll formation. According to Hoagland (1948), certain researches have shown that copper has a role in the synthesis of the porphyrin nucleus and thus in the formation of ' haem ' compounds or of chlorophyll; manganese is known to function in some oxidation systems in plants. Lundegardh (1939) believed it to be of importance in plant respiratory systems. Burström (1938-39) has got evidence of an enzyme system where manganese is involved in nitrate reduction, and boron, like calcium is known to be active in the growth of the meristematic regions of plants. Bean (1942) found a relation between zinc and the peroxidase and catalase activities of plant tissue. Protein synthesis in the plant is markedly influenced through some direct or indirect action of zinc. Molybdenum is known from the work of Spencer *et al.* (1954), Nicholas *et al.* (1954), Nicholas (1957) and others to be involved in nitrate reductase enzyme action. Iron is known to have catalytic effects on chlorophyll synthesis from the work of Bolle Jones (1955). Pandalai (1949) has discussed the different aspects of micro-nutrients in relation to plant life, specially their functions in higher plants as well as the symptoms which their toxicity or deficiency induced in them. Toxicity and deficiency symptoms of most of these elements in plant growth have been carefully studied and specific instances are now known. Some evidence has been reported that amino-acids accumulate in plants that are deficient in some of the above elements, which may be a partial explanation of the symptom manifestation of plants deficient in some of the micro-nutrient elements.

Child (1950) states that there is little information on the micro-nutrient requirements of the coconut palm. Bodin (1929) has claimed that the application of iron salts increased yield of palms growing on coral islands. Innes (1949) in his investigations on the etiology of the " Unknown disease " of coconut palms found no evidence that manganese deficiency was the cause of disease and that the limit of manganese in coconuts (leaf and inflorescence) was probably not above 10 ppm. Sankarasubramoney *et al.* (1952) have confirmed the finding of Innes and found that irrespective of health or disease of the palm, the manganese content varied from traces to 177 ppm in the leaf tissue. Dodd (1929) could find only little or no boron in the coconut fruit and Bertrand and Benzon's (1928) findings are negative for zinc. The whole problem is now under careful study in India and Ceylon.

Nutrient inter-relationships

Apart from the presence in the soil of the necessary plant food factors and a good supply of moisture, it is also necessary that there must be a proper balance between the nutrient constituents present both in the soil and in the plant. These are known to interact with one another in the soil affecting nutrient absorption, and utilisation. The interactions may be grouped as antagonisms and synergisms. All the twelve " essential elements ", viz., nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, copper, zinc, boron and molybdenum as well as the " beneficial elements ", such as sodium, chlorine, silicon and probably others may all be involved in these interactions. The ultimate nutrition of the crop including yields and quality depends both on the levels of the individual nutrients and their relative amounts in the plant tissues. As may be expected, the nitrogen/potassium ratio is very important in palm nutrition. Wallace (1928) has shown that the nitrogen/potassium ratio, if wide, increases leaf scorching while a narrow ratio reduces it. A faulty phosphorus/potassium ratio is known to reduce the nitrogen intake of the palm. Cooke (1950) found that magnesium aids the movement of phosphorus within the plant and that a deficiency of magnesium should, therefore, be expected to bring along a phosphorus deficiency condition in the tissues. This is why the results from the use of balanced and complete fertilisers (applied in certain definite proportions) are much more spectacular than those where single fertilisers are used. The degeneration of the cells of the mid-rib of coconut fronds showing 'streaking' may be due to cell dissociation caused by manurial deficiency (potassium being relatively low according to analysis), exaggerated by unfavourable water and nutritional relationships at the time the palms come into bearing. There is evidence in literature to show that iron and potassium are inter-related in plant metabolism. Wallace and Hewitt (1946) and Bolle Jones (1955) have shown that added potassium was able to cure iron chlorosis probably by the prevention of iron precipitation by the phosphorus present either by conversions of the inorganic to organic phosphorus or by some secondary effect on the organic acid status and cell sap pH. In fact it was found that the soluble iron increased, with potassium supply, showing that the potassium/iron is an important nutrient ratio in the metabolism particularly in the matter of the chlorophyll status of the green leaves. He has also shown that the inter-relationship between potassium and phosphorus approximated to that of synergism.

York *et al.* (1953) have discussed calcium/potassium interactions in soils and plants. According to them, lime influences the level of exchangeable or water soluble potassium in soils and its absorption by plants and they emphasise the need for a balance between these nutrients for optimum plant growth. Salgado (1955*c*) found that potash manuring of coconut palms reduces the calcium uptake as shown by the rise in potassium/calcium ratio, in the leaflets. This observation is in accord with the calcium/potash antagonism postulated by Ehrenberg (1919). Krackenberger and Peterson (1954) in a recent review point out a positive correlation between the phosphorus and magnesium contents of plants or between the efficiency of phosphate fertilisers and the supply of available magnesium. Several such metal inter-relationships have been emphasised by different workers, especially Hewitt (1954), involving copper, manganese, zinc, chromium, iron, nitrogen and molybdenum. It should be expected that in a perennial plant such as the coconut palm these aspects have important significance.

Nutrient removal

From the large amount of soil and tissue analytical data given by Sampson (1923), a nearly correct idea of the amounts of nitrogen, phosphoric acid and potash removed by a crop of coconut could be worked out. It may be seen from the following table that even chemical analyses of the palm differ widely. In the Philippines, the ripe nuts contain more than 2 gm of phosphoric acid, while at Kasaragod (India), it is even less than 1 gm per nut. The potash content in the nuts at Kasaragod is half of that contained in a nut from the Philippines.

Table 36.—Ash analysis of ripe nuts (average per nut in gm) (Patel, 1938)

	Kasaragod nut (Sampson)			San Ramon, Philippines (Copeland)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Husk	1·25	0·18	3·05	1·609	0·017	3·915
Shell	0·45	0·015	0·17	0·660	0·459	0·947
Meat	5·13	0·77	1·35	4·683	1·740	2·475
Water	0·025	0·028	0·33	1·542	0·171	1·313
Total ..	6·855	0·993	4·90	8·494	2·387	8·650

Computations have, however, been made by different workers on the heavy demands of the major nutrient factors by the coconut palm based on different criteria and different figures have been arrived at. This is seen in the following table.

Table 37.—Quantities of plant food ingredients removed from the soil per annum

No.	(In pounds per acre)					Basis	Authority
	N	P_2O_5	K_2O	CaO	MgO		
1.	18	5	38			2,000 nuts per acre per year.	Pillai, 1919.
2.	57	26	85			From one acre per year.	Jacob and Coyle, 1927.
3.	82	37	122			2,800 nuts per acre per year.	Copeland, 1927.
4.	66	27	123	15·7	28·6	Soil rich in plant nutrients.	Georgie and Teik, 1932.
5.	81	36	117			Annual removal from one acre.	Eckstein *et al.*, 1937.
6.	24	12	60			Recommendation for annual addition per acre.	Patel, 1938.
7.	81 to 126	27 to 45	108 to 144			156 mature palms per hectare.	Carvalho, 1947.
8.	26	8	24	13·0	20·0	60 palms per acre with 25 nuts each per annum.	Cooke, 1950.

There is no certainty about the uniformity in conditions like soil type, variety of palm, age of plantation, climatic factors, soil fertility status, soil management practices, etc., which will alter the actual consumption or removal of nutrients. The figures given above are therefore comparative rather than absolute, but however, they emphasise the heavy demands of the coconut palm for the soil nutrient factors. Judging from these figures it is apparent that for the coconut palm, the major nutrients arranged in the order of their importance are as follows: potassium, nitrogen, phosphorus, magnesium and calcium. The following table gives an idea of the distribution of the nutrient contents in the different parts of the palm, the figures being consolidated from those by Sampson.

Table 38.—Analysis of the different parts of a bearing coconut tree (Sampson, 1923)

	Nitrogen, per cent	Phosphoric acid, per cent	Potash, per cent	Lime, per cent	Magnesia, per cent
Root	....	0·043	0·29	0·20	0·68
Stem	....	0·055	0·21	0·27	0·65
Stipule	....	0·029	0·034	0·084	0·065
Petiole and Leaf stalk	0·28	0·17	0·25	0·27	0·44
Leaflet	1·76	0·25	0·56	0·28	0·57
Husk	0·44	0·066	1·11	0·34	0·21
Shell	0·38	0·013	0·14	0·091	0·014
Meat	1·49	0·46	0·80	Trace	0·16
Water	0·50	0·56	6·60	0·69	0·59

Not much work appears to have been carried out on the chemical and physiological changes in the coconut palm related to maturity. Sampson who furnishes the most complete analysis on the coconut palm has stated his views as follows:—

" In the case of nitrogen it will be seen that the heaviest demands are made on the resources of the tree quite late in the development of the fruit, i.e., within the last six weeks or two months. Nearly 75 per cent of the nitrogen removed from the tree when the ripe fruit is harvested is to be found in the meat of the nut. . . . As regards potash, it will be seen that the demand for this commences early in the development of the fruit. . . . The quantity of potash in the meat seems to be greatest at the time when the meat is being laid down, after which it seems to be reduced, when no longer required for this work. . . . The supply of potash seems to be readily forthcoming when it is required. It is probable that, this being a more soluble salt than most other plant foods, there is much more elasticity in the supply, it being taken away from other parts of the plant, resulting possibly in the retardation of growth for the time being, and brought to where its presence is essential. . . . This (potash) is required in large quantities by any rapidly growing part of the palm. Such growing parts are always present. The bud or ' cabbage ' is continually forming new leaves and these leaves are all the time expanding. In the axis of each leaf a flowering branch is normally formed and this in its turn has to grow very rapidly until the flowers expand. Even after this it continues to grow rapidly as the fruits which it carries are swelling and the meat within the fruit is forming. All these places show a concentration of potash. In the leaves also large quantities of potash are required. This is especially the case in the young plant. . . . The plant, however, is able to remove a large part of the potash from any working part of the plant, as this gets past work. Thus in the young tree not yet in bearing, it is seen that there is 41 per cent of potash in the ash of the tender leaf, i.e., the leaf which is still growing. In the fully developed green or working leaf there is only 18 per cent."

We are still much in the dark about the actual nutritional requirements as well as the changes in these requirements of the coconut as it comes into bearing. Roach (1936, '38, '39 & '40) at East Malling has made some studies on fruit trees in plant injection methods with mineral substances for diagnostic and curative purposes. His idea was to determine deficiencies if any, and then to make good the same to enable the plant to grow normally. These methods may be expected to give interesting data if tried on the coconut and some progress is being made by Davis *et al.* (1954) at Kayangulam (India) in this direction.

Dwyer (1937) has carried out injection experiments with coconuts using twelve different substances. Martyn (1948) has tried injections of palms with solutions of salts of magnesium, cobalt, manganese, zinc and iron from suitably placed containers. Salts of copper, sodium, magnesium, zinc and manganese in muslin bags were also introduced into the " hearts " of palms. No positive effects were observed. Work at the Jamaican Department of Agriculture has shown that the use of micro-nutrients and soil fumigations against the Unknown Disease was ineffective. Much more work has to be done on coconuts from the point of view of the interaction of nutrient factors in the soil and their availability to the palm on the one hand and the diagnostic injection methods for curative purposes on the other, especially with regard to the micro-nutrients.

Moisture requirements of the coconut palm

In common with most other agricultural crops, moisture is a great limiting factor in the successful cultivation of the coconut palm. John (1952) observes that proper supply of moisture, either through well distributed rainfall, percolation water or irrigation and sufficient drainage are essential for the proper growth of the coconut. Work on the actual moisture requirements of the coconut palm, however, appears to be very scanty. In making injection experiments, Dwyer (1937) had observed on bright sunny days that hundreds of grams of water are taken up by the coconut palm, almost as quickly as they are introduced. In the early morning and on rainy days the rate of absorption was very slow. During a long wet season when there are numerous consecutive cloudy days as in the West Coast of India for example, moisture absorption and utilisation by the palms are greatly reduced despite the abundance of water present. In the dry season, the rate of absorption is greatly increased due to increase in the transpiration. The palms have natural adaptation in the leaves for regulating transpiration to some extent. There are no water storage organs in the coconut.

Copeland (1931) reports that a coconut palm can absorb 24 litres of water per day from root absorption experiments but from determination of evaporation from the leaves he is inclined to place the figure from 28 to 45 litres. Espino and Juliano (1924) showed that the absorption of culture solutions through roots was more rapid during rainless days than during rainy days. The wind makes a decided difference in the transpiration of the leaves, but makes a much greater one when the leaves are in full sunshine as in the dry season. These workers place the water requirements at 16 litres per day. Whatever be the magnitude of these figures, it is certain that they are of a high order and explain why palms flourish so well at low levels where moisture availability will be greater.

The absorption of nutrients by the palms depends on two sets of factors. Those that occur inside the plant—physiological—and those that occur outside the body of the plant—environmental. The age of the palm, its health, etc., govern the rate and amount of transpiration. Copeland (1931) has studied the loss of water from the coconut on account of transpiration. He found that one leaflet loses in a day 10·8 gm of water. This estimate varies from 28·1 kg to 74·0 kg as the daily loss of water from a mature palm. When unfavourable moisture conditions occur, and in times of severe drought, it is seen that the older leaves fall off or die back with unusual rapidity. This is possibly an economy measure, since it is the older leaves which transpire more water. Thus the tree cuts down its water requirements to a very appreciable extent. Duthie (1938) compared the soil moisture relationships in the soils from healthy coconut beds and from beds carrying palms liable to wilting. In the case of heavy clay soils, he found the slow lateral movement of water, and moisture availability were factors leading to the appearance of diseases. The wilting point in a clay soil may occur when there is less than 13 per cent moisture present in the soils especially in the presence of sodium and magnesium salts. High concentrations of these salts hinder absorption through roots. Copeland investigated in detail the water relationships of the palms during drought conditions. After a prolonged drought in one of the districts of the Philippines, it took the palms years to recover. The vitality of the palms was so severely injured during the prolonged drought, that the return of favourable weather conditions is but very slowly followed by resumption of normal activity. Only a constant water supply can preserve the vitality of the palm.

As the percentage of water to dry matter in a young palm is much greater than in an older palm, the water requirements of a young palm in proportion to its size are greater. This is why young palms are more susceptible to drought conditions. Copeland maintains that the proper physical composition of the soil is of more importance than its chemical composition so long as there is good supply of moisture available to the palms.

The failure of water supply may undo the gain which should be expected after two or three years of fertiliser application. The greater the need for water for normal physiological processes, the greater will be the injury which follows if the supply is inadequate. An expanded root system as a result of fertiliser application, would only bring the trees in keener competition with each other, particularly in close plantations.

The variations in soil moisture during the dry summer months in three different soil types at Kasaragod (India) were studied in the summer of 1951-52 by Verghese *et al.* (1953). They found that regular inter-cultivation and manuring help to conserve soil moisture to a considerable extent, especially in the subsoil layers. This may be due to the beneficial effect of inter-cultivation and incorporation of organic matter. They found that plots having shade effects due to spread of coconut leaves appear to contain more moisture than partially shaded plots. Further work at Kasaragod (Pandalai, 1956*a*) showed that at all times, the moisture content of the laterite soil is much higher than that of red loam and sandy soil at the different depths studied. Maximum moisture content recorded in the first foot of laterite soil was 18·97 per cent as against 11·75 per cent for red loam and 7·17 per cent for sandy soil. In the second foot, the percentage of moisture is more than in the first foot in all soil types and similarly the third foot contained more moisture than the first and second foot, but the difference in the absolute moisture content appears to be more in the laterite soils than in others. These findings are important especially on the West Coast of India where heavy monsoon rains from June to September-October are followed by prolonged period of drought for four to five months from January to May in the year. Tammes (1937) is of the opinion that the number of nuts is controlled not by flower number or pollination but exclusively by the nutritional factors, chiefly water supply. It is interesting to note that the inflorescence of the coconut palm at various stages of development contains 70·17 per cent to 90·07 per cent of moisture (Patel, 1938).

Available potash is a nutrient factor which together with the water supply appears to act as limiting factors in the growth of the coconut palm. They interact in many ways. Under inadequate moisture availability, potash absorption has been shown to be never optimum even in potash rich soils. However, the coconut palm has inherent capacity for adapting itself to its environments and to varying conditions of moisture and nutrient supply. Sampson and other workers also have indicated that a coconut palm shows a very different analysis when grown on a good soil and on a poor soil.

Time factor and fertiliser experiment

In the case of a plant like the coconut palm, an increase in yield as a result of fertiliser application is manifested only from two and a half to three years after the application. An early marked increase in yield can be due to effects other than that of the fertiliser. It is true in the case of the coconut palm that the effect of a fertiliser may be felt over a few years, an aspect on which Copeland has laid much stress.

Normal availability of all the necessary nutrient elements will manifest itself in a healthy growth of the palm and an increase in the general vitality of the tree. As applied to the yield factor, the influence may show first, in the production of larger nuts. Secondly, more nuts may be produced and ripened on each bunch which may hardly be evident within nine months of the application. Thirdly, there may be production of a greater number of bunches of nuts. The rate at which the bunches of nuts follow one another depends upon their rate of development of leaves and the rate at which they begin to be formed. Rate of development appears to be greatly influenced by moisture availability, since it controls the absorption of nutrient elements by the plant. The number of bunches cannot be greater than the number of leaves produced in any given time and this is determined by the rate at which the leaf primordia are produced and developed. Dissection of crowns of coconut trees shows from 17 to 25 distinct leaves which are not ordinarily visible. Microscopical study would, of course increase this number.

Assuming that there are 24 such leaves and that their rate of appearance is 16 a year, the youngest of these will require an year and a half before the tip can be detected in the crown of the tree. After a leaf becomes visible, it requires at least six months for the production of flowers and still another nine months for the production of the fruit. Under these natural conditions, it will take two years and nine months before an improvement in the cultural conditions can increase the production of a marketable crop of coconuts. These facts point to the long ' lag ' before which fertiliser makes its effects manifest in such a perennial crop as the coconut palm. Its first visible effect may be upon the growth of roots or of leaves both directly and indirectly. Chiefly through its effect upon growth, a fertiliser is expected to increase the rate of formation of organic material by the leaves, and only an increase in the assimilation activity of the leaf can influence the production of a crop. Thus, it may be seen, that three years is a reasonable minimum before the beneficial effects of added fertilisers to coconut palms can be realised. The greater the activity in root growth, the greater is the ability to absorb water and the nutrients from the root environments and from a larger bulk of soil from which food supply could be drawn. All these facts according to Copeland, make the effects of the fertiliser to be felt for a very long period. Adequate cultural practices should be carried out, in order that the fertilisers may do their work. Supply of soil moisture is very important in order that the tree may properly develop additional leaves and fruit clusters which have been formed in the " cabbage ". According to Copeland (1931), ' Good treatment of the coconut is a full system of procedure, not a single act nor a spasmodic burst of attention '.

Considerable research work on the mineral nutrition of perennial crops such as the apple, the plum, the pear, etc., have been carried out. Such precise work has yet to be done on the nutritional requirement of the coconut palm.

Principles of manuring

The capacity of soils to supply plant nutrients deteriorates on continued cultivation. Fertiliser practices in coconut gardens after a few years of cropping thus need occasional revision to meet the changing conditions of the nutrient status of the soil. Thus, for practical manuring, it is important to know how far the effect of the plant nutrient depends on the presence or absence of another and to what extent cumulative excess of a major nutrient may adversely affect palm growth. Reviewing these aspects Cooke *et al.* (1950), state that there is no experimental data available on these difficult and involved questions. This state of affairs shows that manuring of the coconut palm could be done only on an arbitrary basis, based on practical farming experience and not with any precise knowledge of the soil or palm requirements. The coconut palm is unique in that once it starts flowering, the production phase lasts almost throughout the year and all through its life. Therefore, there is bound to be a steady utilisation of food material by the coconut tree and consequent depletion of plant foods from the soil. The average annual loss of the important plant foods from an acre of coconut garden has been computed by several workers and is given in table 37. Estimates are not available of all the other elements which are required for the proper sustenance of the trees and the production of nuts. For the proper maintenance of coconut plantations and obtaining good yields, judicious and regular manuring is necessary and this has to be an annual practice. Dwyer (1938) has stated that there is a tendency for copra from trees growing on exhausted soils to become much thinner. It is known that the drain of manurial constituents by a heavily producing palm is very considerable and when that has taken place over a series of years, such effects are sure to influence adversely the growth characteristics of the palms and even to mask the most favourable hereditary characters.

A great majority of the soils in which coconuts are grown in India are found to be deficient in organic matter which is considered very necessary for the proper maintenance of soil structure, and moisture conservation and for obtaining maximum benefit out of the application of fertilisers. Attempts have, therefore, to be made to ameliorate these conditions and this can be done by incorporating into the soil bulky organic manures like farm-yard manure, composts, or by a regular system of applying green manures grown *in situ*.

In loose coastal sandy soils, the application of manures and fertilisers should not be expected to give very good results since the nutrients are likely to be leached and carried away depriving the coconut palms of the best benefit if they are not applied at the proper time and supplemented by bulky organic matter. Laterite soils on which there is a good acreage of coconuts in India, are of inherently low fertility and tend to be deficient in all plant nutrients. Here there is need to supply all N, P and K ingredients in the form of manures. Bulky organic manures with top dressing of N, P and K will suit this soil best. Coconut plantations on laterite areas during the initial years appear to be highly productive but unless adequate manuring and soil management practices are given, the plantations deteriorate steadily. Alluvial soils are naturally rich in plant food factors. Sandy soils are not. Peaty soils as a rule contain more organic and less of mineral matter. Soils which have received adequate quantities of ameliorative supplements such as silts or press mud, etc., need not receive heavy fertiliser additions as these materials themselves have poly-manurial values as shown by Sankarasubramoney *et al.* (1952) and Pandalai *et al.* (1953).

Fertiliser use depends to some extent on the available supply of water for the use of the plant. In localities which have pronounced dry and wet seasons, they should be applied at the proper time. In dry season, water supply should be available for irrigation and during rainy days leaching of nutrients should not take place.

The manurial trials of new replantings in Ceylon have proved conclusively that replanting in a soil on which coconuts have been growing for sixty years or more is futile, unless the condition of the exhausted soil is improved by manuring. Manured " replants " gave good yields in six to seven years, This proves that manuring of exhausted soils is a necessary prerequisite for undertaking replanting. (Salgado. 1955 *b*.)

It appears to be the view of some coconut growers that the long continued use of artificial fertilisers exhausts a coconut palm and that the palm would suffer severe set-back when the fertiliser application is discontinued. Pandalai (1956 *b*) has discussed this position and argued that the need is for a careful and judicious application of both organic manures and chemical fertilisers when both soil conservation and increased yields would be assured. The prolonged use of improperly balanced fertiliser mixtures should be avoided as far as possible.

Fertiliser application to a large extent depends upon the method of handling the grove, whether or not catch crops are grown, what they remove from the soil or contribute to it. These aspects are described under catch crops. Soil exhausting crops, particularly potash loving, such as sugarcane, pineapple, banana, tapioca, etc., should not be grown in coconut groves due to the possible competition for their potash needs as may be seen in Fig. **62**. All these four crops are potash exacting and in a mixed garden will act detrimentally to the coconut palm. These, therefore, should not be grown mixed together unless they are liberally manured, particularly with potash.

Certain weeds found growing in coconut gardens are often rich in potash even upto three per cent on a dry weight basis. These, thus require prompt eradication.

Visual soil characteristics may not always be found reliable as a guide to fertiliser treatment for crops to be grown on it. Patel (1938) thus cites the example of two light sandy soils one overlying a gravelly subsoil and the other overlying a silty subsoil which gave a good and meagre response respectively to potassic fertilisers. This shows the necessity for discovering the peculiarities of each individual soil in order to practice fertiliser economy. It also shows that for a perennial plant as the coconut palm, the subsoil conditions are important, not only from the point of view of the soil nutrient content, but also from the aspect of water table, drainage, permeability of the soil, etc.

The soil system is such a dynamic one that quantitative changes in plant food ingredients are constantly taking place. Often, the tendency will be for the soils to get enriched due to appropriate soil changes such as when conditions favour nitrification and nitrogen fixation. Often there will be loss of fertility when the soluble nitrates and potash are leached away or when soil erosion takes place in heavily rain affected slopes of sandy and sandy loam soils ; loss of nitrates can take place by the activity of denitrifying bacteria. The organic matter content of the soils and their nitrogen content are closely associated and the carbon/nitrogen ratio of a soil orientates its fertility status. The dissipation of organic matter tends to decrease soil nitrogen and methods which increase the organic matter raises the same. Upon the presence of organic matter depend the microbiological processes of the soil which enrich or impoverish it depending upon the existing conditions. The removal of plant food in crops under irrational systems of farming in which there is continuous cropping and no attempts made to return the elements of fertility to the soil is a very serious factor leading to decreased productiveness.

THE MANURING OF COCONUT

It is now well recognised that the analysis of soil samples from coconut gardens does provide indications of major deficiencies but that no reliable recommendations could be based on such data unless it is correlated with accurately designed field experiments carried out for a fairly long period. The different aspects of coconut manuring which need investigation include : the effects of major and minor elements, the effects of different methods of application of manures, time of application of the manures and the forms in which these are best chosen, i.e., organic, inorganic and green manure, etc. Much of the manurial practices done in coconut plantations at present are not based on strict fundamental knowledge about the nutritional requirements of the coconut palm.

The literature on the manuring of the coconut palm reveals that although some empirical experiments were carried out in some coconut growing countries, comprehensive investigations have been in progress only in Ceylon. A start in this direction has recently been made in India also. The causes for this state of affairs are not far to seek. The following are among some of the difficulties which beset systematic work with coconuts.

(1) Difficulty of laying out statistically designed experiments due to the lack of uniformity in experimental material.

(2) Lack of knowledge of the previous history and the practices carried out prior to the start of manurial trials.

(3) The comparatively large extent of area required for experimentation which increases considerably the soil variability factor.

(4) Differential response of individual trees to manuring.

(5) Difficulties involved in the supervision of harvesting and recording of yield data all the year round.

(6) The considerable effect of weather on the annual performance of the palms and the consequent need for continuing the experiment for long periods.

(7) The long ' time lag ' before conclusions on the manurial effects could be drawn.

It may thus be seen that the results of most of the experiments reported so far were obtained under the above mentioned conditions. This has been so in the past and will always remain a bottle-neck in the matter of most investigations with the coconut palm. Nevertheless, empirical information of practical value has indeed been obtained. Manurial responses are also determined by a number of other factors such as the physical properties of the soil, nutrient availability, nutrient balance in the soil and in the palm, as well as the lime status of the soil.

The earliest reports on the manurial experiments on coconuts have come from Ceylon in the beginning of this century. Thus Harbord (1913), Bamber (1914), Lyne (1915), Rajpakse (1921, 1923), Joachim (1929 *a*, *b*) and others have discussed the problem. The last mentioned has reported upon the statistical examination of the data of manurial and cultural experiments carried out at Chilaw, during 1917 to 1928.

Briones (1931) made a study of the salt requirements of coconut seedlings grown in pots and found that the application of ammonium sulphate was beneficial and that moderate quantities of sodium chloride appeared to be invigorating while a heavier application was harmful. He also noted that the palm tolerated heavy additions of magnesium sulphate. In the same year, McClelland (1931) reported results of experiments in Porto Rico with fertilisers on coconut palms and variation in palm productivity. He got only very inconsistent results which did not enable him to recommend any particular fertiliser as suitable for coconuts. A report in the Tropical Agriculturist, Ceylon (1931) dealing with the subject of coconut manuring concludes by saying that only inconsistent results could be obtained and that the yield depended more on the type of the coconut palm than on the fertiliser used. Jacques (1932) published his results on the manuring of coconut palms in New Caledonia in which he found that potash is the main manurial requirement of the palm. He found that phosphoric acid and common salt are also necessary and that the composition of the kernel should form a guide to the use of manures.

Belgrave and Lambourne (1937) have furnished records on the cultivation and manuring of coconuts in Malaya taken in 1936 and showed that no significant response was obtained to manures, lime and surface treatments given in the heavy coastal clay soils. An increase in yield, however, was obtained on a poor light soil but was not sufficient to pay for the cost of the treatment. Wilshaw (1941) confirmed the above results in Malaya, but also showed that there was some response to phosphate manuring, this expressing itself mainly as an increase in the number of nuts. He found that lime dressings alone gave an increase in yield of good nuts as well as in the weight of copra per nut and observed that lime exerted residual beneficial effects. Foster (1937), in Ceylon, was able to obtain on light sandy loam soils significant responses to nitrogen and potash each applied at 0·63 lb per palm every year and none to phosphoric acid. The response to potash was considerably more in the presence of nitrogen and phosphoric acid than in their absence.

Valenoba (1935) reported results which suggested that young coconut plants are heavy consumers of potassium and phosphorus. According to him ' amophos ' at a rate 1 lb per plant is one of the best fertilisers yet tried for young coconuts. Tammes (1938) has presented data from trials of various cultivation systems in North Celebes. Fertiliser applications have proved profitable only where there is potash and phosphate deficiency. Green manuring according to him, never increased copra yield. Clean weeding for a year produced results on exhausted soil equal to those of manuring but it cannot be carried out on sloping ground on account of erosion risks. Child and Salgado (1941) have studied the effect of manuring coconut palms on the oil and protein contents of the copra. There was no effect on the oil or nitrogen percentage of the copra even after the different fertiliser treatments. According to a report of the Department of Agriculture, Jamaica (1949), best yields were obtained with N P, N P K and farmyard manure (10 cwts per acre) ; considering individual treatments, nitrogen had good response.

Verteuil (1934) found in Trinidad from single plots containing six trees that the application of mixed fertilisers and lime increased the yields. Murray and Lucie Smith (1952) also working in Trinidad found that increased number of nuts was secured from ammonium sulphate applied at 3 lb per tree in neglected plantations, poor bearers showing greater increase in yields than good bearers. They found no response to phosphorus or potassium in the absence of nitrogen and have suggested that several more trials are needed before more definite conclusions particularly in regard to the yield of copra per nut could be drawn. Response was generally absent where the trees were already yielding well prior to manuring. They have discussed the difficulties involved in fertiliser trials with coconuts.

Sporadic attempts at studying the response of the coconut palm to manuring have been made in Ceylon even from the early years of this century. Salgado (1946 *a*, *b*, *c*; 1947 *a*, *b*, *d*; 1948) considers most of the above experiments were unsatisfactory as they represented only extreme soil types. The principal manurial experiments carried out and still in progress in Ceylon are laid out at the Bandirippuwa Estate and at the Ratmalagara Estate.

The N P K manurial experiment in Ceylon

An N P K manurial experiment with three levels of nitrogen (0·0 lb; 0·5 lb ; 1·0 lb), three levels of phosphoric acid (0·0 lb; 1·0 lb ; and 2·0 lb) and three levels of potash (0·0 lb ; 0·75 lb ; and 1·5 lb) applied once in two years was in progress since 1936 at the Bandirippuwa Estate where the soil is sandy loam over lateritic gravel. This area had been under manuring even before 1936. The following are the main conclusions drawn from the experiment.

(1) Nitrogen gave a highly significant response in the second year after the start of manuring, later on it progressively declined and actually depressed the yields after the tenth year. Seasonal vagaries of wet and dry weather had little effect on the response to nitrogen. A high nitrogen level was found to adversely affect the response to potash. As a source of nitrogen there was little to choose between cynamide, ammonium sulphate (inorganic forms) and groundnut cake (organic form).

(2) There was no response to phosphoric acid in any year since the start of the experiment.

(3) Potash was found to be the dominant manurial requirement of the palm for the soil types of the station. Potash applied at 0·75 lb per palm produced significant response only in the fifth year while with the higher dose of 1·5 lb a significant increase was obtained in the third year. Though the response was found to be influenced to some extent by seasonal factors, it went on progressively increasing and reached the peak in the fifteenth year as can be seen from the data given below taken from Salgado (1952 *b*). Cowie (1951) has discussed this aspect.

Table 39.—Pounds of copra per acre, K_2O applied biennially

Year	0·75 lb	1·5 lb
1936	26	50
1937	47	80
1938	47	114
1939	28	120
1940	190	249
1941	122	196
1942	352	470
1943	300	407
1944	362	546
1945	329	422
1946	312	447
1947	382	512
1948	442	582
1949	401	546
1950	542	711
1951	664	846

While the increase in yield of copra is largely due to the increase in yield of nuts, the increased copra content per nut had a remarkable influence on the total output. In the case of manured trees only less number of nuts were required to make a candy of copra as can be seen from the following table.

Table 40.—Number of nuts per candy of 560 lb of copra

No potash	1,281
0·75 lb ,, ...	1,164
1·50 lb ,, ...	1,140

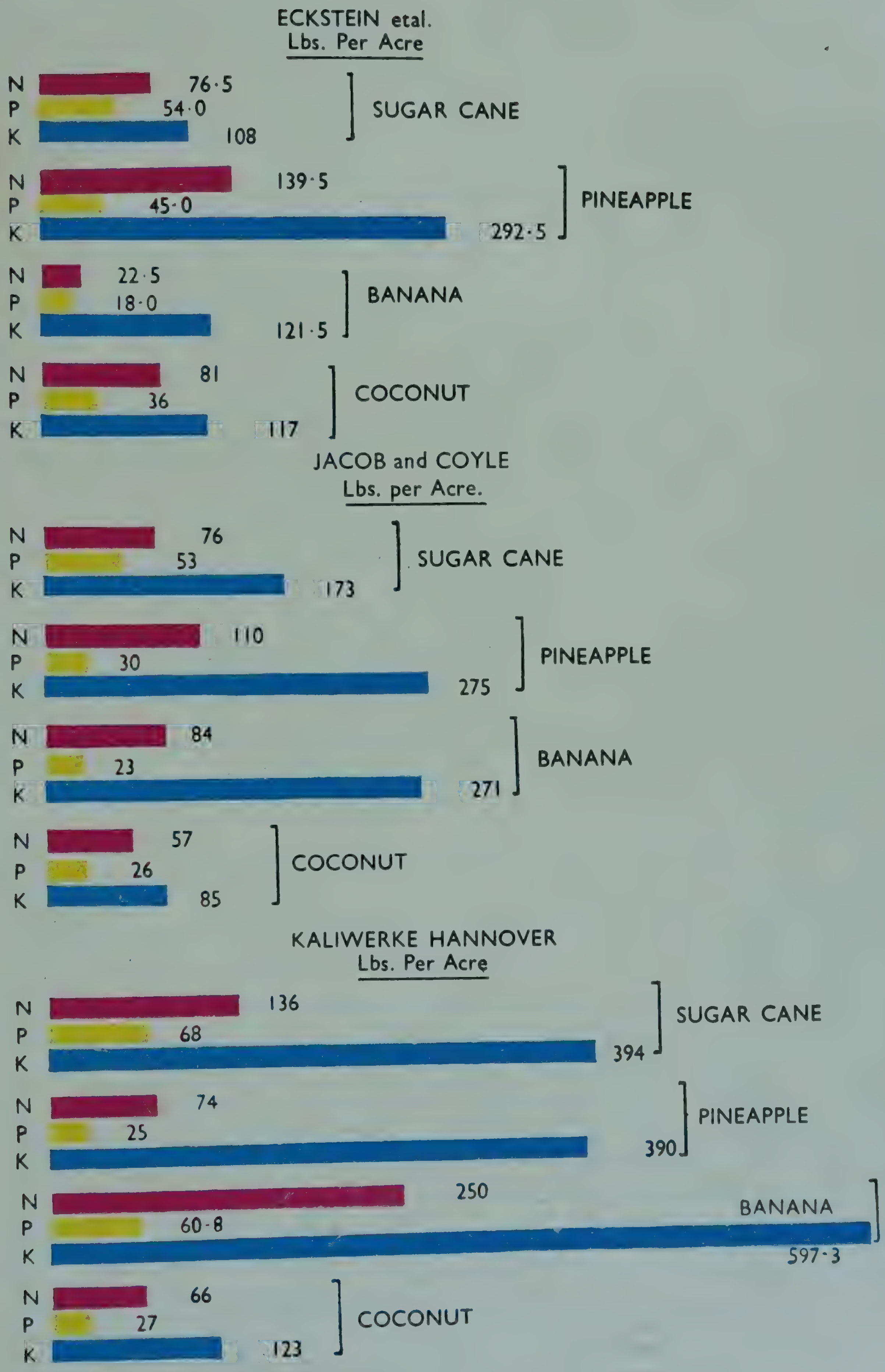


Fig. 62. Annual exhaust of nutrients by different crops

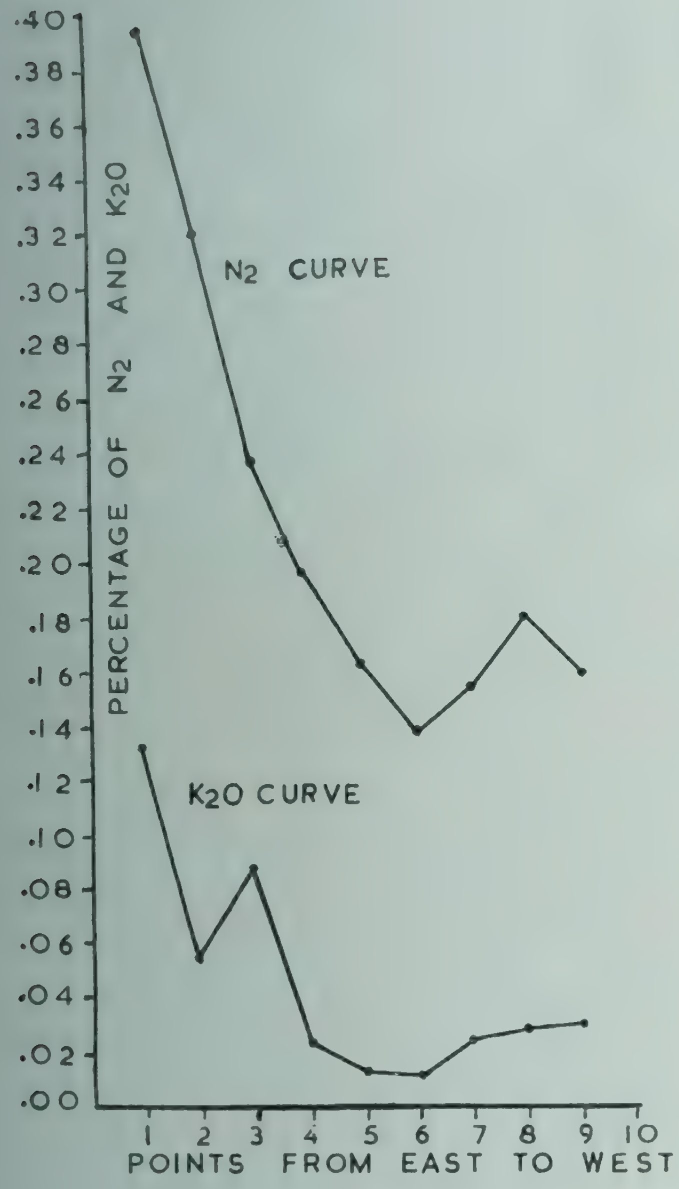


Fig. 63. Nitrogen and potash content of the soil

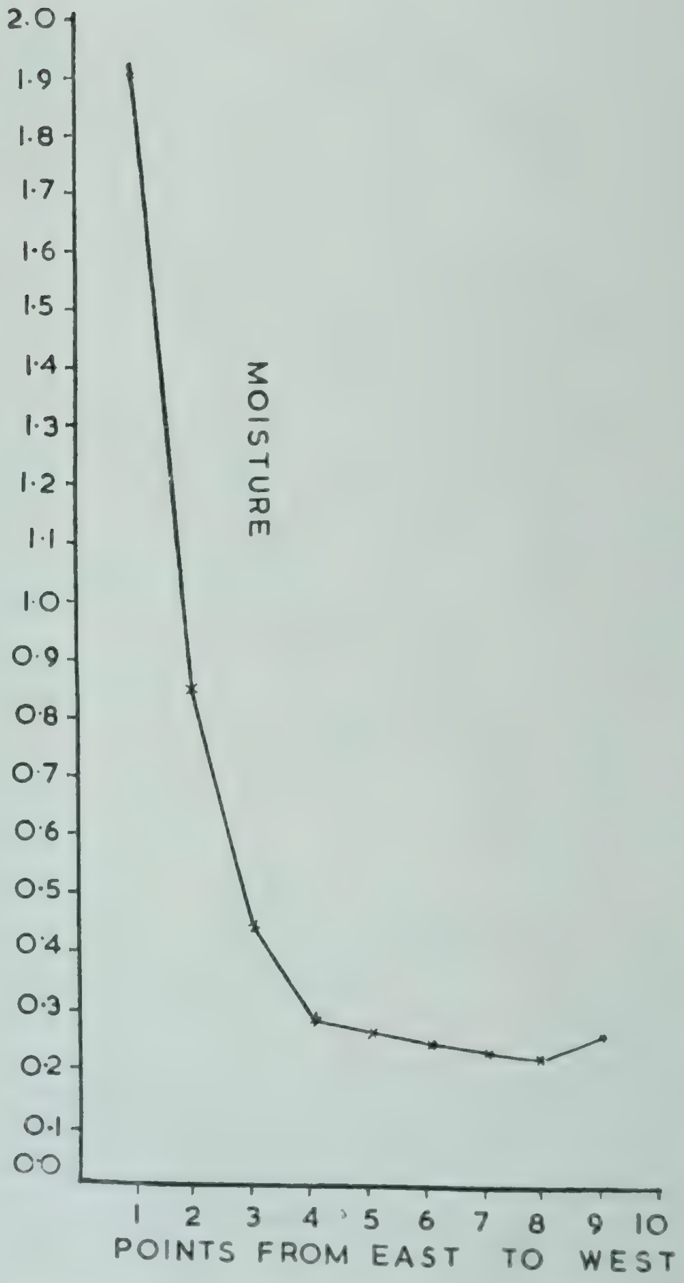


Fig. 64. Percentage of moisture in the soil

Halliday and Sylvester (1954) commenting upon phosphorus manuring of coconuts in Ceylon, state that while at Bandirippuwa, with adequate reserves of phosphorus, there was no response to phosphorus application, experiments in the poor laterite soils of Veyanagoda and Ahangama with low phosphorus resources on the other hand, gave spectacular responses to application of 0·60 lb of P_2O_5 per palm every other year, as is seen from the following table.

Table 41.—Yield of Copra (lb/acre)

Year	Complete fertiliser N P K	Without Phosphate	Difference due to application of phosphate
1939–40	553	490	63
1940–41	627	562	65
1941–42	998	809	189
1942–43	1,073	744	329
1943–44	1,096	774	322
1944–45	1,287	828	459
1945–46	1,115	763	352

Based on the yield data these authors prescribe phosphate doses for coconuts on different soil types. The increased copra out-turn in this case also is attributed to the increased yield of nuts as well as to the improved copra content, per nut.

Response to phosphoric acid was obtained also at Ratmalagara where the soil is reported to be loamy. At this centre highly significant response was seen from the rate of 1·0 lb per tree once in two years. This is clear from the following table.

Table 42.—Increased yield of copra due to application of phosphate

Year	lb of copra per acre
1944-45 (2nd year after the application of manures)	144
1945–46	152
1946–47	316
1947–48	350
1948–49	290
1949–50	556
1950–51	404
1951–52	472
1952–53	572
1953–54	690

In an attempt to explain the difference in response to phosphoric acid observed at Bandirippuwa and Ratmalagara, Salgado (1955 *a*) comes to the conclusion that the levels of available phosphates as determined by the citric soluble or Troug methods have little prediction value as a basis for assessing the need for phosphate manuring (Salgado, 1952 *a*). In this connection he postulates the need of organic phosphorus in the nutrition of the coconut palms. The Ceylon experiments have also conclusively shown that phosphate tends to get accumulated to a large extent in soil and exerts long sustained residual effects. Cooke (1932), believes that besides phosphoric acid, potash also accumulates in the soil but nitrogen has no such effect. An experiment to compare the effects of applying each of the nutrients N, P and K in circular trenches as opposed to broadcasting and ploughing was in progress since 1948-49. No significant differences between the two methods of application have been reported. Pieris (1952) recounting thirty-five years trials on a coconut estate in Ceylon, has emphasised the importance of bulky organic manures and of improving soil structure. He has also dwelt on the ill-effects of over-fertilising and of disturbing wet soils.

Patel (1938) has reported in detail about the observational trials carried out on a deep, red sandy loam soil of the Central Coconut Research Station at Kasaragod (India) with different sets of arbitrarily selected manurial mixtures, containing ammonium sulphate, super phosphate, potassium sulphate, lime, ash, cattle manure, fish guano, coconut cake, common salt and green manure, in different quantities and combinations.

Based on observations carried out for eight years, it was concluded that ammonium sulphate 1·5 kg and ash 10 kg per tree per year formed the best manure followed by cattle manure at 50 kg per tree. It was also stated that the increase in yield obtained depended upon the initial bearing capacity of the tree. Low yielding palms were considerably benefited but not high yielding ones.

Later experiments carried out on the same soil showed: (1) 2 kg of ammonium sulphate per tree per year gave better yields than 1·4 kg; (2) ammonium sulphate can be replaced by groundnut cake on equivalent nitrogen basis; and (3) ash can be replaced by sulphate or muriate of potash on equivalent potash basis.

A comprehensive experiment with N P K each at three levels with and without a green manure crop recently initiated in the same soil type is now in progress at the Central Coconut Research Station, Kasaragod.

Patel has also given an account of the interesting results of manurial trials carried out on gravelly laterite soils of the Agricultural Experimental Station, Nileshwar-I (Pilicode — India). These experiments showed: (1) groundnut cake 4 kg can be substituted by ammonium sulphate 1·4 kg without affecting the yield; (2) applying the manures (2 kg of ammonium sulphate, 14 kg of wood ash, 1 kg of bone-meal and 45 kg of green leaves) by broadcasting and covering or in basins eight feet radius and one foot deep is better than applying them in trenches two feet wide and one foot deep dug in between rows of trees; and (3) among the different sources of potash, muriate of potash appears to be better than sulphate of potash or wood-ash on equivalent potash basis.

Patel has pointed out that as the experiments mentioned above in Malaya and Trinidad were started in 1931 and as the yields only upto 1933 have been taken into consideration, much emphasis cannot be laid on these results. Citing the results of Baconno as well as Espino (1919-20), Patel (1938) concludes that the findings in India, Ceylon and the Philippines regarding the usefulness of ammonium sulphate is uniform.

Manurial experiments carried out at the Coconut Farm, Ochira, Kerala State by Menon and Nair (1951) from 1939 onwards using mill-ash, rock phosphate, groundnut cake, green manure, etc., in different combinations showed that under the conditions of the experiment, the highest average yield was obtained in the set in which green manure, groundnut cake and mill-ash were used as the manure mixture. In spite of the fact that the area had a good percentage of diseased trees, there was indication that nitrogen and potash could bring about some response.

In a private communication (1956) the Director of Agriculture, Gold Coast has stated that fertiliser trials with both major and minor elements and various cultural trials have as yet produced no significant results.

In the Coconut Fertiliser Demonstration Scheme operated on the West Coast since 1952 by the Potascheme, Bangalore, India (Malye, 1956), good response to the application of N P K fertilisers at 0·4 kg N, 0·4 kg P_2O_5, and 0·75 kg of K_2O per tree per year was obtained in all soil types except the loose sandy soils in Travancore-Cochin. Bearing in mind the inherent difficulty of agronomic research with the coconut palms particularly in small holdings on the West Coast of India, these results point to certain conclusions. Taking all the fields at all the centres consisting of about 22,000 individual trees distributed over 178 fields in the long belt extending from Cape Comorin in the south to Badagara in the north, it is seen that the N P K plots have recorded increased yields upto 17 per cent. Where the moisture conserving capacity of the soil was higher or in localities with well distributed rainfall, the response was more in fields receiving regular intercultural operations. In the diseased areas of Travancore-Cochin, the effect was to some extent masked by the high incidence of the disease. Manurial plots receiving regular fungicidal spraying showed improvement over the unsprayed plots.

The results of the different manurial experiments described above are not strictly comparable because of the wide differences in the soil and climatic conditions of the regions, the non-uniformity in the quality and quantity of the nutrients supplied, the duration of experiments, etc. However, certain broad generalisations on the different aspects of manuring are possible and these may be summarised as follows :—

1. There is general response to the application of potash and nitrogen, while response to phosphoric acid is seen only in certain restricted situations.
2. The response to manuring is conditioned to a large extent by the availability of nutrients in the soil, but there is no clear idea as to the threshold values below which response could be expected. The non-response to manuring in the heavy coastal clay soils of Malaya is probably due to their high natural fertility. Potash content is reported to reach as high as 0·8 per cent.
3. A minimum of three years appears to be a reasonable period for the first response of the trees to manuring to become manifest.
4. There is general agreement that initially high yielders do not respond as much to manuring as low and medium yielders. This indicates the possibility of selective manuring of the trees especially when the prices of fertilisers are high.
5. Regarding the effect of manures on characters other than the yield, Salgado (1946 *a*, *b*) is of the opinion that (*a*) nitrogen has a beneficial effect on female flower production, potash has little effect and phosphoric acid, a definite depressing effect; (*b*) on copra content, nitrogen has an adverse effect, as a higher number of nuts are required to produce a candy of copra and (*c*) potash has a very beneficial effect, while phosphoric acid has no effect. According to Child and Salgado (1941), the oil and protein content of copra are not influenced by the different nutrients. Patel (1938) reports of having obtained the highest quality copra and oil from plots receiving complete manure containing N P K.
6. Experimental evidence is still too meagre to express any conclusive opinion regarding the alleged superiority of organic forms of fertilisers over the inorganic forms.
7. Broadcast application of manures is seen to be as good as the application in circular basins or in trenches. Application in linear trenches in between rows of trees is not as good as the other two. It should, however, be realised that the experiments have been carried out in gardens where the palms have been planted as a pure crop. This situation is never obtained in small holdings where the palms would be irregularly planted among miscellaneous other forms of vegetation. Under these conditions, application of manures in circular basins or trenches is to be preferred for the following reasons:—
    (1) The highest concentration of roots being close to the palms would result in maximum utilisation of nutrients.
    (2) There is less fixation of phosphates in the soil as the ratio of soil to fertiliser is less than when broadcast over the soil.
    (3) When manure is applied broadcast, the entire area has to be ploughed or harrowed to cover the manures. Loss of fertiliser applied to the surface is possible through run off.
    (4) Surface manuring may encourage surface rooting which may make the palms susceptible to drought.
    (5) There may be rank growth of weeds competing with the palms for plant food, which will cost more to control.
    (6) This method, largely in favour with the growers, has stood the test of time.

Much difference of opinion however still remains in the matter of response by coconuts to manurial applications. The absence of uniform experimental material, and clear knowledge about the appropriate nutritional requirements, and the long lag period before results of indicative value could be obtained are responsible for this state of affairs. Probably the use of radioactive tracers in investigations on coconuts would give quicker and more accurate assessment of some of these problems.

Common salt in the nutrition of the coconut palms

Either as a direct manure or as an indirect soil ameliorant, the addition of common salt in coconut gardens is a very old and popular practice among coconut growers. Difference of opinion prevails on the beneficial effects of this material. It is very widely applied to the soil as well as to the top of the palm often admixed with a little wood ash. In lateritic soils, the addition of common salt in the pits for planting seedlings is known to soften the laterite bed and help early penetration of the tender roots. The view that common salt helps to conserve soil moisture has not yet been proved by experiments. The results of several studies in different soil types have shown that the concentration at which common salt may exert a beneficial effect on soil moisture conservation is very high and in this concentration may adversely affect normal plant growth. Whether sodium chloride can release available potash from the soil has also been not definitely proved by experimental data. As a matter of fact, there is very little evidence that adding sodium salts to a soil increases the availability of the soil potassium. Growers have a feeling that common salt when applied to the soil has an effect of bringing down the percentage of incidence of barren nuts.

In the case of coconut seedlings, Briones (1931) found that moderate quantities of sodium chloride appeared to be invigorating, but a heavier application was rather harmful. Jacques (1932) believes that just as potash and phosphoric acid, common salt is also required for the nutrition of the coconut palms. Indeed, Cooke (1950) has computed that 2 kg of soda per year are removed from an acre of coconuts. In a recent report by Salgado (1951), it is stated that after fifteen months of treatment, seedlings on a rocky laterite soil at the heavy rate of 0·5 kg per plant per month gave a distinct difference in vigour, size and colour between the treated palms and the untreated. Salt is now being applied in the above dose to the young palms in the Bandirippuwa Estate to test the validity of the belief that coconut palms growing in areas remote from the sea do benefit by salt application.

The coconut palm is a semi-halophyte, being able to live in situations where its roots come in contact with such salt concentrations as would be lethal to many other plants. This shows that it can resist the action of salt but it need not be that it requires salt. There appears to be a misunderstanding as to the actual amount of salt concentration prevailing on coastal sands on which the coconut palms thrive well. The coastal soils are not at all saturated with salt on account of the fact that the underground water in the coastal areas flows seaward from higher inland regions. In many parts of the coast, therefore, fresh water could regularly be struck on land within a few yards of the waves. Copeland (1931) has emphasised this fact. Petch (1909) has also discussed the theories and facts which have been published with regard to the use of salt in coconut cultivation. Salt sprays are liable to deposit small quantities of the substance on the soil surface, but due to the extreme mobility of the chloride ion these are leached into the subsoil especially when there is rain.

Analysis of husks of nuts collected from the sea coast and inland have also shown that proximity to the beach has no bearing on the quantity of sodium chloride removed in the husks. Experiments at Kasaragod (India) as well as Vohidatra Estate and at the Ivolina Experimental Station, Madagascar, in which sea water and sweet water were used for irrigation of palms during summer, have shown that the palms do not show any difference in behaviour. Indeed, it is now recognised that sea water is not only harmless but serves well for irrigation where sweet water is not available. The possibility of using water with a salinity varying between 0·4 per cent and 2·8 per cent, the same as in sea water according to the report of the technical committee on marginal lands (1951), has been examined in Ceylon. It is known that the coconut palm can endure brackish water but the upper salinity limit is not known. A suggestion has been made that salt addition to soil has a slight sterilising action on it. This cannot also be viewed seriously since if such sterilisation takes place, it can kill beneficial organisms as well.

Some workers have suggested (Cassidy, 1951), salt damage as a probable cause of some diseases of the coconut palm. This factor cannot be assessed fully at present with the meagre experimental data now available. Excess salinity of soil and subsoil water undoubtedly has in some areas disposed trees to disease conditions. There are certain gardens on the sea coast, where, the brackish water used for irrigation has

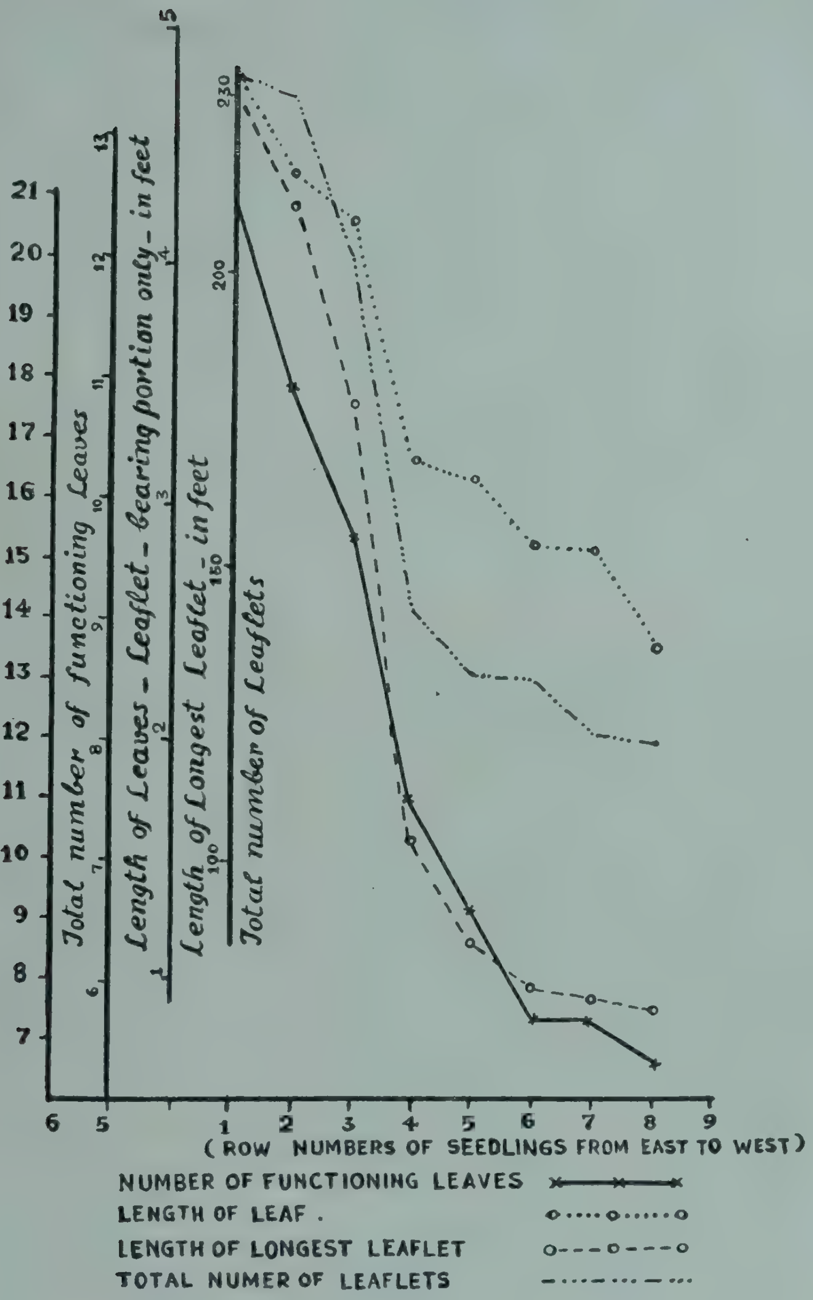
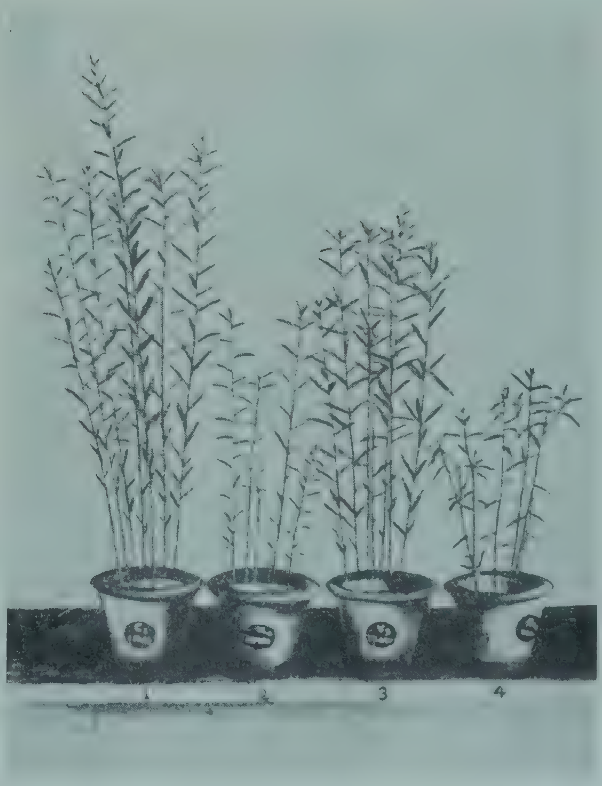


Fig. 65. Relation between soil fertility and growth of coconut seedlings

Fig. 66. Sunn-hemp as indicator plant for potash and calcium deficiency



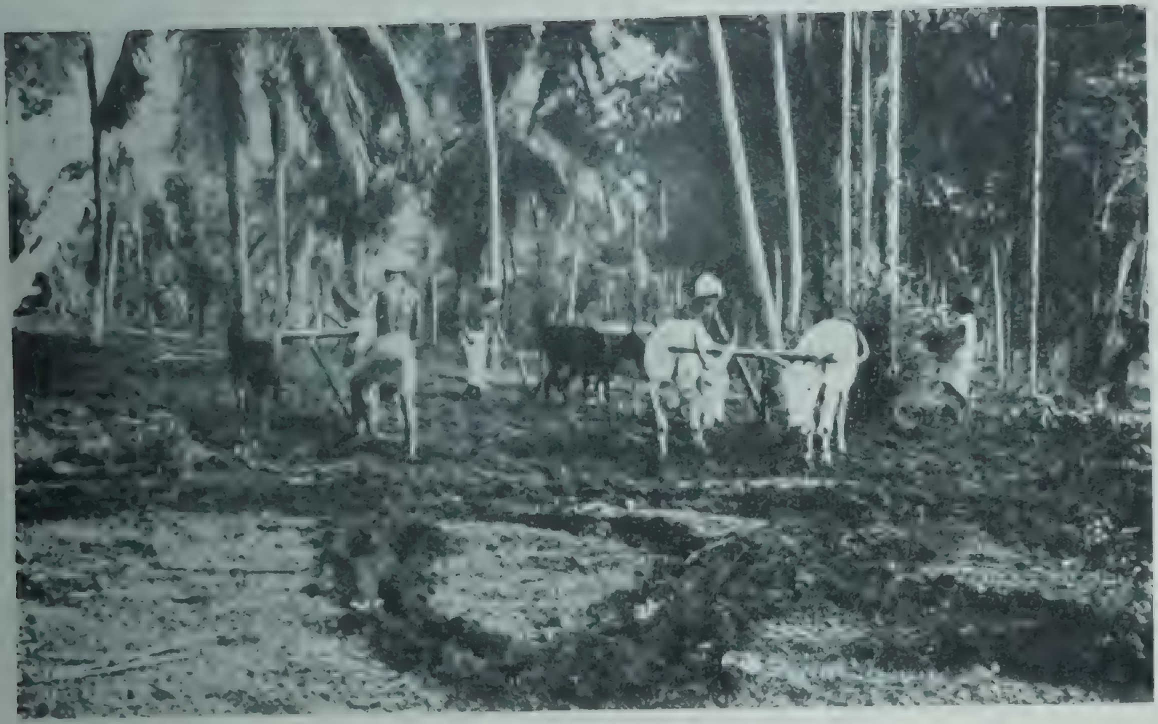


Fig. 67. Cultural practices—ploughing

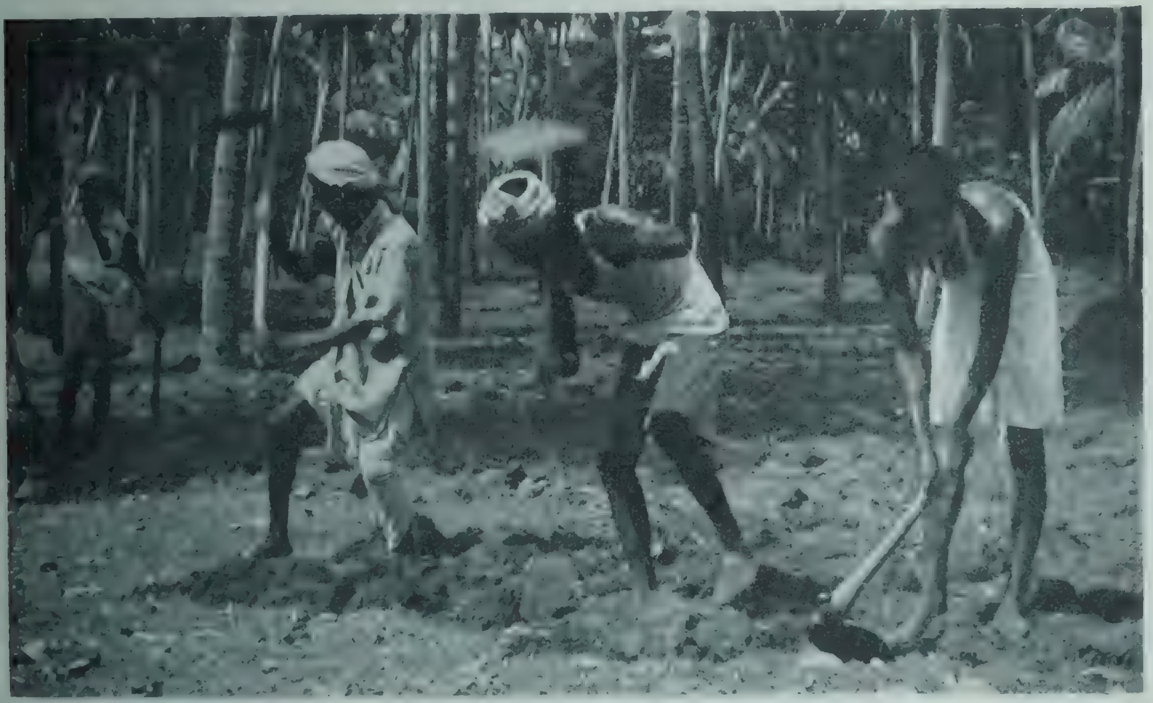


Fig. 68. Cultural practices—Digging

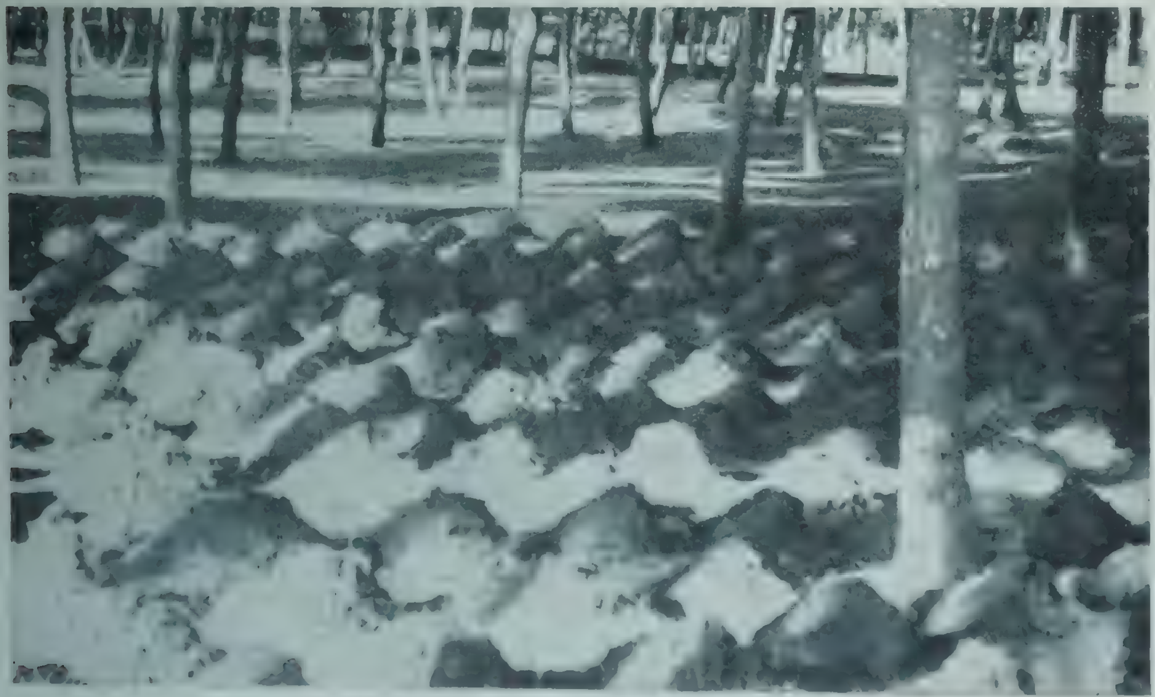


Fig. 69. Cultural practices—forming mounds

caused wilting of palms. It has to be remembered that salt being a rather mobile constituent of the soil, the possibility of its getting concentrated in amounts enough to upset the physiological equilibrium of the palm is remote especially in lands receiving plentiful rainfall.

These considerations indicate that while the coconut palm can tolerate salt concentrations in the soil to a considerable extent and often absorbs salt into the system and removes it in the different products such as husks, it cannot be asserted that it has any special preference for it. Its partiality for coastal soils thus appears to have little to do with the alleged salt concentrations of these areas. Only further systematic work can give clarification of the present rather conflicting views on this subject. Nevertheless, it has to be conceded that the use of common salt has been and still continues to be very popular among coconut growers as a beneficial agent in the health and productivity of the coconut palm (Pandalai, 1957 *b*).

Methods of increasing soil fertility in coconut gardens

The use of farm yard manure, green manures, compost, fertilisers, soil amendments and soil ameliorants as well as adequate soil management will increase the fertility status of coconut soils (Salgado, 1952 *c*). Other important factors contributing towards productivity in soils are improved drainage, cultivation practices, and crop rotation. Many localities have good natural drainage by reason of their topography or a more or less porous subsoil or both. Areas not so favoured have to be drained by digging suitable channels. This will prevent water-logging and consequent anaerobic soil conditions. The main object of cultivation, ploughing, harrowing, rolling, etc., is to effect a good tilth which may be defined as a fine and friable condition of the soil allowing root penetration and root spread. The operations serve to conserve soil moisture and allow beneficial microbiological processes to take place in the optimum manner enriching the soil with mineral plant food. Good and proper cultivation has been shown to be as essential to vigorous coconut growth even as the application of plant nutrients. The desirability of rotation of crops in inter-cropped coconut gardens is perhaps primarily due to its beneficial influence in keeping down weeds. There is a certain amount of economy of plant food factors in the soil on account of the different requirements of the non-competitive inter-crops grown, as well as the depth of the soil from which they draw their nourishments. Rotation practices also assist in maintaining a favourable tilth and in soil moisture conservation. That manuring a crop like the coconut is of paramount importance has already been sufficiently emphasised. The agricultural value of manures (including green manures) fertilisers, etc., and the quantities to be used for the different soil types, the manner of using them, the time of application, etc., are treated in further detail in Chapter VIII.

Soil testing as an aid to fertiliser dosage

In attempting to assess the fertility of soils in relation to the growth of crops, according to Wallace, (1950) two general methods of approach are available. The first is to examine the soils including their crop producing capacities and their chemical, physical and biological properties and the second, the special features of the plants concerned likely to provide relevant data. The coconut is a crop which will amply repay investment, if good judgement and sound advice are used in planning the fertiliser problems. A knowledge of the climatic potential of the area, the general soil conditions and the level of management on the farm are important factors for consideration. In this connection soil tests may give an adequate aid to plan the recommendations. Among other aspects one should have a knowledge of the reserve phosphorus present or being accumulated in the soil as a result of past fertiliser practice as well as a knowledge of the need for a high potash fertiliser as either a starter or a top dressing. One should also know the level of organic matter for maintaining soil tilth and as a source of nitrogen. An accurate measure of the soil reaction as well as magnesium availability is also necessary. McMurtrey (1947) has pointed out that magnesium deficiency is usually most prevalent in deep sandy soils and is accentuated by excessive rainfall. Gammon *et al.* (1953) have shown that the quantity of magnesium in sandy soils is correlated with the content of organic matter. That the magnesium content of soils is not always a good index of the adequacy of the element was shown by Garner *et al.* (1930). These considerations are important from the point of view of the magnesium requirements of the coconut palm growing on sandy soils in the high rainfall areas of the tropics. Soil analysis as pointed out earlier, to a more or less extent, gives a rough answer to all these problems and indicates the relative availability or deficiency of plant nutrients in the soils. However, according to Salgado (1950 *a*), 'there seems to be considerable amount of popular misunderstanding in the use of soil analysis. So far, we have some data on the phosphate needs of coconut soils as shown by such analysis, but it has severe limitations when applied to Ceylon soils'. Different soil management practices do from time to time, change soil nutrient levels to such an extent that greater variations may be found on adjoining farms than between soils with widely different characteristics.

Indeed, it is well known that from the point of view of soil fertility, no two plots of land are, or could be identical. Anandan *et al.* (1950) have emphasised the intimate association of soil fertility for proper growth and performance of coconuts even in localities climatically and otherwise suitable for them. The following graphs (Figs. *63* to *65*) give a good illustration of these aspects in a plot in the Central Coconut Research Station, Kasaragod (India).

In poor soils, it is thus clear, only substantial and judicious investment of capital could adequately repay coconut farming. In such areas, coconuts require regulated tilling operations coupled with heavy and regular dosages of manure, particularly when they are in the bearing stage.

Nutrient deficiency diagnosis

A procedure which can provide some evidence on soil fertility factors in relation to growth of plants is the one in which plant diagnostic methods to determine the nutrient status of the crop plants are used. The methods involve quantitative and qualitative procedures and some are designed to correlate chemical data of soils (Bray, 1948), and plants (Goodall and Gregory, 1947; Lundegardh, 1943), with crop yields. These methods have now been widely used particularly for perennial crops at Long Ashton by Wallace (1943-44, 1950), Hewitt (1950, 1951, 1952) and at East Malling by Roach (1938, 1939, 1940) and Roach and Roberts (1945). Diagnostic methods take account of the number and quantities of all the twelve essential as well as the beneficial elements required for plant nutrition, and their functions in the soil and in plant tissues. The majority of plant nutrient problems are concerned with deficiency of nutrients occurring either as simple or multiple deficiencies. Others relate to injurious excesses, often amounting to phyto-toxic concentrations. There are evidences, though not yet conclusive of both these types affecting the coconut palm. The main point of practical interest is usually that of sub-optimal yields, but where unsatisfactory nutritional conditions are severe, pathological conditions may develop as the result of improper functioning of the physiological processes, the so-called functional or physiological diseases or mineral disorders.

The diagnostic methods include:

(1) The visual method in which plants develop well defined and characteristic signs of the disorders particularly in the leaf as well as in other organs of the plant;

(2) The foliage spraying and painting methods in which advantage is taken of the fact that the leaf is able to absorb from its surface suitable concentrations of nutrient salts giving quick and spectacular effects;

(3) Leaf, stem and trunk injections in which solutions of solid salts of the nutrient elements are put into the vascular tissues from where they are absorbed and translocated in the usual way, the method being only qualitative and useful for recording deficiency symptoms;

(4) Foliar diagnosis introduced by Lagatu and Maume (1924) and very widely used, even though it only serves to give a comparative idea. The method also involves analysis of plant tissue for nutrient content. Based on this, interpretation of seasonal trends and the past events in the plant may be possible;

(5) The leaf analysis method of Lundegardh (1945) involving the principle that only the nutrients absorbed by plants and not their concentrations in the soil are significant for growth and yielding useful information on fertiliser effects; and

(6) Those using plants as nutrient extractants from soils according to the well known Mitscherlich and Neubauer methods discussed by Stewart (1932).

The above methods concern basic physiological concepts of the processes of plant nutrition, such as absorption and translocation of the nutrients from soil to the leaf, their interactions and relative mobilities within the plant tissues, and the fundamental relationship between the concentrations of ions in the plant, particularly in actively functioning leaves as also the accumulation of organic products determining the yields and quality of the crops. The field kit designed by Nicholas (1948) at Long Ashton has been found to be useful for coconut growers as a rough guide to their problems in coconut soils and may help diagnostic work in coconut estates. In using plant diagnostic methods as a means of assessing fertiliser requirements, Wallace (1954) has emphasised the value of certain soil characters in helping in the diagnostic procedures and in the interpretation of the data on pH, calcium carbonate content, soil depth and texture, organic matter and drainage. Consideration of these will save much time in diagnosis, in indicating the probable major problems and in enabling sound advice to be given on the needs of fertiliser dressings. Thus, correlating crop response with the nutrient status of the soil under field conditions is one of the reliable ways of estimating accurately the needs of the crop.

Although such information is now available with regard to a number of crops in relation to the fertility problems of the soil on which they grow, practically no work on this basis has been so far carried out on the coconut palm. It is clear, that useful information will undoubtedly be available regarding the nutrition of the coconut palm by these methods, provided the experimental techniques to accomplish the trials are standardised. This task in the case of the coconut palm is not an easy one. However, attention is now being devoted to these aspects at the Central Coconut Research Stations at Kasaragod and Kayangulam (India) and methods are being standardised (Pandalai 1956 *a*, 1957 *a*). Menon (1953) has attempted to use the well-known indicator plant method for assessing the soil fertility problems in relation to coconuts at Kayangulam. Among the indicator plants tried, sunn-hemp (*Crotalaria juncea*) has been found to be useful to denote potash and lime status of coconut soils (Fig. ***66***). Davis *et al.* (1954) have also extended root injection methods to assess nutritional problems of the coconut and preliminary results achieved indicate that useful guidance could be derived in the study of the nutritional problems of the coconut by these methods. Salgado (1950 *b*) has shown that estimation of potash in nut water affords a relatively simple method of assessing its availability in the soil in relation to the needs of the coconut palms. He has claimed superiority for this method over the conventional method of soil analysis, as, in his view, the former measures the ' capacity ' factor whereas the latter measures only the ' intensity ' factor. While soil analysis attempts to measure the nutrient supply of a limited strata of the soil, 'capacity factor' takes into account not only the nutrient status of the soil but also the volume of the soil available for the roots of the palm to grow in search of plant food. Nut water is considered analogous to plant sap in indicating the physiological status of the palm and of the soil conditions in which it grows. Data have been given to show the increase in potash content of coconut water as a result of N P K manuring. This opens up an interesting field of study, and further work on this would surely increase its utility to the ordinary grower. However, Cassidy (1952) has written on the potash status of coconuts in Vitilevu and states that only in very few nuts did the water contain less than 2 gm per litre of potassium which is the border value of deficiency.

Without adequate tests it is not often possible to determine the limiting factors in plant growth. In the absence of suitable knowledge about these factors, it may often be uneconomic to add fertilisers to the soil in the interests of farm efficiency and good plant growth. In order to maintain balanced nutrient status, only those factors deficient in the soil need be added. The tilting of the carbon/nitrogen ratio in soils by the addition of any one of the agents increasing either humic matter or nitrogenous matter is an instance of offsetting soil fertility. Glut supply of nutrients or glut availability of these in the soil often cause only ' luxury ' consumption and depressed crop yields both in quality and in quantity. These aspects could be controlled by a proper knowledge of the soil and the requirements of the palms. For the coconut, these are as important considerations as with any short duration crop. John and Verghese (1951) as well as John (1952) have, after careful consideration of the different aspects of soil requirements, availability of fertilisers and other related factors, given thoughtful formulae for manure schedules to be adopted in coconut gardens in different soil types.

Liming of coconut soils

In order that the best effects of fertilisers are derived by the palms, great care has to be exercised in liming the soils. Over-liming of soils create potash and boron deficiency as well as the condition known as lime induced chlorosis in palms. Where liming materials not containing magnesium are used, magnesium tends to become a limiting element and may be applied as magnesium compounds. Sampson (1923) has suggested that lime is useful to replace potash in the soil. In some places according to him, quick lime or freshly slaked lime gives remarkable results in increasing the yield of the coconut. Lime is also said to have the effect of " sweetening " the soil which, if it is a coastal soil, rich in organic matter may be acid. Many coral-derived soils under tropical conditions which have a vast acreage of coconuts are low in lime content due to excessive leaching of the surface layers. This is a factor which leads to their stickiness and liability to water-logging. According to Ekman (1955), the best utilisation of growth factors by plants is obtained at about pH 6·0 and at equal concentrations of Ca and K. Disturbance in nutrient uptake under acid conditions may be compensated by increasing the Ca concentration in the soil. Since the activity of poly-valent nutrient elements in soil is much reduced by the greater absorption on the soil colloids of divalent than monovalent ions, a good potassium status (300 kg) of exchangeable potassium per hectare requires ten times more calcium (400 kg of calcium oxide) for adequate nutrient balance. In addition to regulating base saturation and pH, and thus affecting weathering and humus formation, liming stimulates mineralisation of organic nitrogen and phosphorus, improves nitrification and reduces aluminium and manganese toxicity in very acid soils of low organic matter content. According to Belgrave and Lambourne (1933*a*, *b*, 1934), liming is of benefit on exceedingly acid soils (pH 2·0 to 3·5) under which soil condition severe yellowing of the palms and in some cases even sudden wilting have been noticed. Salgado (1947*c*) is inclined to the view that the actual lime requirement of coconut soils is small and should be adequately met by the calcium in the bone meal, super phosphate, cynamide and other fertilisers applied.

The coconut thrives best at pH conditions just on the acid side of neutrality, though Sampson (1923) is of the opinion that it appears to be a plant which needs a soil giving an alkaline reaction. The fact has, however, to be conceded that the coconut palm can adapt itself to quite a wide range of pH conditions in the soil. According to Troug (1948), all the essential and beneficial elements of plant nutrition are available to the plants provided they are present in the soil, so long as the pH is in the range of 6·5 and 7·0. When the biological regime in the soil is most satisfactory, nutrient conditions are favourable without being extreme and phosphorus availability at a maximum, while soils with higher pH tend to make the micro-nutrients unavailable with the exception of molybdenum. Since lime serves a twofold function in the soil, firstly as a plant nutrient factor and secondly as the agent adjusting the soil reaction and hence the availability of other soil nutrients to plants, the liming of coconut soils appears to be rather important. Indeed, the changes in the soil due to liming are so many, so complex, and so inter-related, that it is not possible to ascribe the influence observed to any one factor. Tests for the evaluation of the lime status of soils are probably the most dependable of all tests from this point of view.

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CHAPTER X

PLANTATION MANAGEMENT

The coconut is essentially a cash crop though in certain countries such as India, Ceylon, etc., it is also a food crop in the sense that coconut kernel and oil invariably find a place in the dietary of the inhabitants. The main consideration in plantation management should, therefore, be to maximise the net income from it and this can be achieved only by increasing production, reducing costs, creating additional sources of income, proper disposal of major and minor products, etc. (Krishna Marar, 1955). The first two are the most important and fall under the domain of soil management.

SOIL MANAGEMENT

General considerations

Proper and efficient soil management is essential to ensure profitable production and to maintain and preferably to increase the fertility status of the soil. A good soil management programme aims at keeping the soil in good condition where the physical, chemical and biological properties of the soil are optimum for crop growth. The physical condition of the soil should be such that it should be able to store sufficient water for the use of the palm, providing at the same time enough aeration for the healthy growth of the roots and for the efficient working of the beneficial micro-organisms. From the chemical point of view, the soil should be able to provide the crop with both macro and micro-nutrients in sufficient quantities and in proper balance in accordance with its special requirements. Good soil management will also have to deal with factors directly harmful to the growth of the crop such as drainage, water-logging, excessive dryness, soil erosion, toxic conditions, etc. In short, soil management is intimately connected mainly with the factors of soil structure, soil reaction, organic matter content, soil conservation and nutrient status which individually and collectively influence soil fertility.

Soil structure

The structure of a soil is determined by the arrangement of its particles. It is greatly influenced by tillage, granulation and organic matter content. Crumb structure which permits free drainage, aeration and enhanced water-holding capacity is reported to be the best which a proper soil management programme should aim at creating. Sandy and heavy clay soils are naturally poor in structure and attempts should be made to improve them if good crops are to be raised.

There is need for free circulation of air through the soil for plant growth. The plant roots require oxygen in order to develop energy needed to take in nutrients from the soil solution. Oxygen is also essential for the activities of the micro-organisms to proceed in a satisfactory manner. In the absence of free circulation of air, carbon dioxide accumulates and brings the activity of the roots and soil bacteria to a standstill.

Considerable quantities of water are required by the palm for its growth and this, it takes in, through the roots from the soil in the form of soil solution. Water has many functions in the nutrition of the plant. Apart from other functions, it dissolves plant nutrients from the soil and transports them to the root system and provides the medium through which the nutrients taken from the soil and substances synthesised in the plant are translocated.

Soil reaction

Soil reaction which is denoted by the conventional notation of pH of the soil solution is a very important characteristic of the soil. A neutral soil which is neither acidic not alkaline is represented by pH 7. Lower values than this indicate acidity and higher values alkalinity. The coconut palm is adaptable to a wide range of soil reaction.

The soil pH influences the availability of nutrients in the soil and the development of toxic conditions. Thus, in the region of neutrality, all the major plant nutrients such as nitrogen, potassium, sulphur, phosphorus, calcium and magnesium are readily available to the palm. As the soil tends to become more and more acid, these become less available. Moreover, iron and aluminium occur in a soluble form and they tie up phosphate present in the soil and that applied in fertilisers. The work of the beneficial soil bacteria also gets inhibited. With increasing alkalinity of the soil solution, there is not much adverse effect on the availability of nitrogen, potassium, sulphur, calcium and magnesium, but the availability of phosphorus, boron and manganese gets reduced.

Soil organic matter

Organic matter in the soil is composed largely of material of vegetable origin. It exerts considerable influence on the physical and chemical constituents of the soil. Since it can absorb several times its dry weight of water and retain it for the use of the crop, it is very effective in moisture conservation. In heavy soils, its incorporation has the effect of loosening the physical structure and improving aeration thus making the soil easier to work ; while in light soils it tends to bind the soil particles together and improve water-holding capacity. The organic matter is also a store house for plant food as on its decomposition, large quantities of nutrients become available to the crop in a readily assimilable form. The development and activity of the soil micro-organisms get stimulated. Organic matter also enables the soil to resist rapid changes in its reaction and prevents the development of toxic and deficient conditions. Thus the fertility of the soil in a variety of ways is closely related to the organic matter content and its periodical replenishment in tropical soils where it gets exhausted quicker is therefore essential.

Soil conservation

It is now well recognised that erosion is responsible to a large extent for soil depletion and that maintenance of soil productivity is intimately bound up with its control. The important factors of erosion are : type of soil, intensity of rainfall, slope, exposure of soil surface, soil tilth and permeability of sub-soil. Wherever hazards of soil erosion exist, suitable measures should be taken to control them.

Soil nutrients

That the coconut palm needs large quantities of nutrients for successful growth has been referred to elsewhere. To the extent possible, optimum conditions should be provided so that the crop can use the nutrients that the soil can supply. If the soil does not contain all the nutrients or contain them only in insufficient quantities, the deficiencies have to be made up to ensure satisfactory performance from the crop.

MANAGEMENT PRACTICES

The poor productivity of most of the coconut plantations is undoubtedly due to faulty, improper or inadequate soil management. A fuller appreciation of this fact and a systematic adoption of improved practices will help to step up production.

The important soil management practices that are to be given due consideration in relation to the coconut are : tillage, drainage, mulching, erosion control, cover cropping, manuring, replenishing organic matter, husk-burying, use of soil amendments and ameliorants. The need for and the importance of each of these practices will differ with the soil type, situation, condition, etc. For example, in a heavy soil, the primary object will be to make it more porous, whereas in a lighter soil, the main concern will be to improve its water and nutrient retaining capacity. Again, in a sloping land, more than anything else, the essential need is to conserve the soil. Salgado (1954) has discussed about some soil management practices that are adopted on coconut estates in Ceylon.

(*a*) Tillage

In coconut gardens, inter-cultivation or cultivating the interspaces is the main tillage operation and consists of ploughing, harrowing and digging. The objects of tillage in a coconut garden may be summed up as follows :—

(1) To make the soil receptive to the first rains after a rainless period, and also to make it retain more moisture.

(2) To produce favourable tilth or soil structure for the development of roots, thereby increasing the available feeding area for the palm.

(3) To improve the aeration of the soil resulting in increased bacterial and chemical activity which in turn increases the available plant food in the soil.

(4) To kill weeds and thereby conserve both plant food and water for the palm.

(5) To incorporate organic matter into the soil.

There is still confusion and controversy regarding the need for and the best form of tillage to be adopted for coconut plantations. The beneficial effects of systematic tillage have been testified to by many workers. At the Central Coconut Research Station, Kasaragod, observations carried out over a series of years have shown that yields can be increased and maintained at high level by systematic cultivation alone. In a regularly cultivated plot (without manuring) the mean yield was as high as 48 nuts per tree as against 10 nuts obtained from an adjacent completely neglected plot. Variations in annual yields were much less in the regularly cultivated plot (coefficient of variation, 17 per cent) when compared to the variations in the neglected plot (coefficient of variation, 73 per cent). Huggins (1930) has referred to the valuable results obtained by regular cultivation alone in East Africa. According to Bamber (1914), ploughing the land twice annually was as beneficial as manuring. Cooke (1932) also refers to an instance in Ceylon where a regularly cultivated and weeded portion of an estate gave on an average 55 nuts per tree, whereas the neglected portion gave no yields worth recording. Salgado (1946) states that on good coconut soils, yields upto 3,000 nuts per acre can be obtained by judicious cultivation alone. The Ceylon Coconut Commission has testified to the fact that estates which had been systematically cultivated had withstood the vagaries of weather much better than the others. In a recent manurial versus cultivation experiment in progress in Ceylon, ' ploughing once in two years ' gave increased yields over ' no cultivation ' in 10 out of 11 years for which results are available, though the differences proved significant only in two years. The absence of good response might be due to the fact that the interval between successive ploughings is too long to be of real benefit. Tammes (1938) reports that in Celebes, occasional ploughing had given no crop increase, but clean weeding produced results equal to those obtained from manuring. In Malaya, regular cultivation had beneficial effects on sandy soils, but not on heavy coastal clay.

It is now fairly well established that the benefits of cultivation are primarily due to the removal of weeds which compete with the main crop for soil moisture and nutrients. When there is a general moisture deficiency, weeds can prove a definite limiting factor to the healthy growth of the coconut palm.

Under the soil and climatic conditions obtaining on the West Coast of India, regular cultivation is found to help in conserving soil moisture, through the combined effects of weed removal, better percolation of water to sub-soil layers and reduced loss of moisture by evaporation from soil surface (Patel, 1938; Verghese *et al.*, 1953; Krishna Marar, 1953).

Cultivation is an important item of expenditure in the maintenance of a coconut garden and it is therefore necessary to limit it to the irreducible minimum. To get the maximum benefit from cultivation, a number of factors have to be taken into consideration, such as form, frequency, time and depth of inter-cultivation, etc. (Krishna Marar, 1953).

In the coconut tracts of India, different cultivation practices such as ploughing, digging with mammoty (spade), opening basins and covering them, forming mounds and subsequent levelling, etc., are being followed by progressive growers (Figs. *67*, *68* & *69*). The cost involved varies with the different operations and a correct evaluation of them under similar conditions is necessary before a particular practice is advocated. Ploughing is the cheapest of the above, yet a small grower may prefer to dig up his garden with mammoty. Where the soil is light, cultivation can be done with hoes or harrows with ease and rapidity at less cost. Cultivation is to be practiced at the proper time, taking into consideration the incidence and distribution of rainfall, soil type and slope of the land. The soil should be ploughed only when it contains proper amount of moisture lest it should spoil the structure of the soil and create hard pans. In sloping lands, ploughing may be done along the contour after the heavy monsoon rains are over, in order to avoid the risk of soil erosion.

The depth of inter-cultivation, has to be determined with reference to the depth of soil, the height of water table, the condition and distribution of the root system, etc. Shallow cultivation should be preferred in order to avoid damage to the root system. This is particularly important when the area of root spread is restricted or the palms are weak, because then rejuvenation of roots does not take place satisfactorily. If the soil is deep and the palms healthy, cultivation has the effect of forcing the roots to go to lower layers where they do not suffer much during drought periods.

The garden should be cultivated when the soil has become hard and compact or when it is foul with weeds. Too frequent cultivation can prove harmful under tropical conditions, as it may accelerate the depletion of soil organic matter.

The weeds may be incorporated into the soil by ploughing or by burying them in trenches where they will rot in course of time and augment the organic matter content of the soil. As the primary object of cultivation is to reduce weed growth, it should be done before the weeds flower and set seeds.

(*b*) Drainage

The coconut palm cannot tolerate water stagnation for long and consequently puts on poor and stunted growth giving a few nuts under marshy and continued water-logged conditions. Such areas are met with in all the coconut growing countries. Where this condition does not admit of satisfactory amelioration, coconut should never be grown. Where the area can be easily drained, coconut can be made to bear satisfactorily. In low-lying lands where the water table remains high throughout or which suffer from water stagnation during certain periods in the year, drainage channels should be dug to take away surplus water. These drains should be periodically repaired and kept in good condition and should not be allowed to get choked up with weeds, rubbish or earth.

(*c*) Mulching

Mulching is the practice of covering the surface of the soil with a layer of vegetable waste material, with a view to keeping the surface layers at a more even temperature, more permeable to water and for reducing weed growth. Though considerable literature has accumulated on the effects of mulching on other horticultural crops, comparatively little is found reported in respect of the coconut. The materials that can be used for mulching are husks, leaves and fibre dust (in areas near coir retting centres or fibre processing mills). These materials though available in large quantities in Ceylon and other countries, are difficult to obtain in India for mulching purposes. Mulching with husks upto a distance of 2 m from the base of the bearing tree is being done in Ceylon and has been reported to help in conserving moisture and preventing weed growth. In India, mulching with dry coconut leaves during summer did not have any marked beneficial effects on the palms growing in sandy soil. Mulching should be done at the end of the rainy period. The preliminary observations on the use of coir dust as mulch in Ceylon appeared to show that it can conserve soil moisture but has no effect on immature nut-fall.

(*d*) Erosion control

Soil erosion is a really serious problem in gardens raised on hill slopes, particularly in areas where heavy rains are received. The loss of fertile top soil exposes the roots of the palm and creates plant food deficiencies with the result that the palms look diseased and become unproductive. The importance of taking adequate measures for the control of soil erosion cannot, therefore, be overemphasized. A number of methods such as terracing, contour bunding, cover cropping, building crescent bunds, etc. suited to different situations have been suggested by Livera (1947), Gorrie (1950 *a, b, c,* 1951), Perkins (1950), Fredrick (1953), Middleton (1954) and Nethesinghe (1954).

(*e*) Cover cropping

The growing of cover crops in coconut plantations is now becoming more and more popular in coconut growing countries. Cover crops are those crops which are able to make vigorous growth and cover the ground densely in a short period of time (Fig. ***70***). As distinct from a catch crop, a cover crop is chosen more with regard to the interest of the main crop than of the cover crop itself. The following are the benefits expected by growing the cover crops.

(*i*) Prevention of soil erosion.
(*ii*) Smothering of weeds thus reducing weeding costs.
(*iii*) Addition of organic matter to the soil and thus maintaining the structure of the top soil.
(*iv*) Improving aeration of the soil.
(*v*) Protecting the soil and roots of crops from excessive heat of the sun.
(*vi*) Conservation of fertility by using available plant food which might otherwise be leached away.
(*vii*) Fixing of atmospheric nitrogen from the air in the case of leguminous plants.
(*viii*) Taking away moisture and nutrient supply from the soil, thus reducing the amounts available to the trees. This will check fresh wood growth and produce conditions favourable for proper ripening and better colour of the fruits.

Some of the objectionable features of growing cover crops are that, under certain conditions, they may compete with the main crop for plant nutrients and soil moisture and reduce yields.

In coconut gardens, cover crops have been successfully used for the conservation of soil and control of weeds. The usefulness of cover crops in suppressing the pernicious weed, *Imperata cylindrica* which is a threat to coconut plantations in Ceylon, Malaya, Philippines, Indonesia and South Sea Islands has been well established. Cover crops suitably managed will also increase the organic matter content, maintain the fertility of the soil and conserve soil moisture. In Ceylon, the soil under cover crop had more nitrogen when compared to a soil without cover. At the Central Coconut Research Station, Kayangulam (India) the temperature of the ground under a cover crop of tropical kudzu (*Pueraria phaseoloides*) during the hottest part of the day was 10°C to 20°C lower than an adjacent bare land. There was no marked difference between the fertility status of the two plots.

The cover crops to be grown in coconut gardens should be tolerant of shade and preferably low growing. The latter requirement arises from the fact that gathering of nuts that fall in the ripe stage cannot be done satisfactorily if the cover crop were to grow high. *Calopogonium mucunoides, Centrosema pubescens* and *Pueraria phaseoloides* are recommended in Ceylon. On the West Coast of India, *Calopogonium mucunoides* appears to be more suitable than the other two, since, under the seasonal conditions obtaining there, the crop is found to get completely dried up during summer months leaving a thick mulch of dead leaves. Under the favourable climatic conditions in the Philippines, this crop is reported to behave as a perennial.

Once established, the cover crop should not be allowed to grow uncontrolled lest it should affect the coconut palms. In Ceylon, in dry areas under conditions of low rainfall, the cover crop has been reported to have caused a set-back to the growth of palms. In Malaya, *Centrosema* had retarded the growth of young and old palms on overdrained soil. The cover crop may be harrowed once or twice a year when the cover is thick or may be ploughed in or dug up with a forked mammoty once every two years. The treatment of cover is best done during the rains so that it can quickly regenerate itself. It will also be a safe precaution to plough or dig the cover only in alternate rows, so that, in case adverse weather conditions affect regeneration, the plants from the untreated portion can grow and spread into the adjoining areas.

The above-mentioned crops are not useful to the grower in any other way and hence are suitable only for large estates. The small growers would prefer to utilise the area for growing crops which are of some utility to him and for such people, crops like cowpea may be more acceptable.

Methods of growing and utilising cover crops have been described by Salgado (1951), Krishna Marar (1954), Kurup (1955) and Albuquerque and Mohammed Ibrahim (1956).

(*f*) Manuring

There is no gainsaying the fact that coconut palms do respond to proper manuring particularly for the reason that coconut soils in general become deficient in major plant nutrients. Even if the soil is initially fertile, continuous removal of plant foods from the soil in fairly large amounts, consequent on the unique bearing feature of the palm, is likely to create nutrient deficiencies some time later, unless proper manures are used to make good the loss (Fig. *71*). To forestall such an eventuality, it is a wise precaution to adopt a proper manuring schedule from the beginning itself.

The different aspects of manuring of the coconut are dealt with in detail elsewhere.

(*g*) Replenishing organic matter

The need to keep the organic matter content of the soil at a satisfactory level has already been explained. This is of particular importance to the coconut soils of the West Coast of India which are very deficient in organic matter. Green manuring would probably be the best solution to overcome this deficiency.

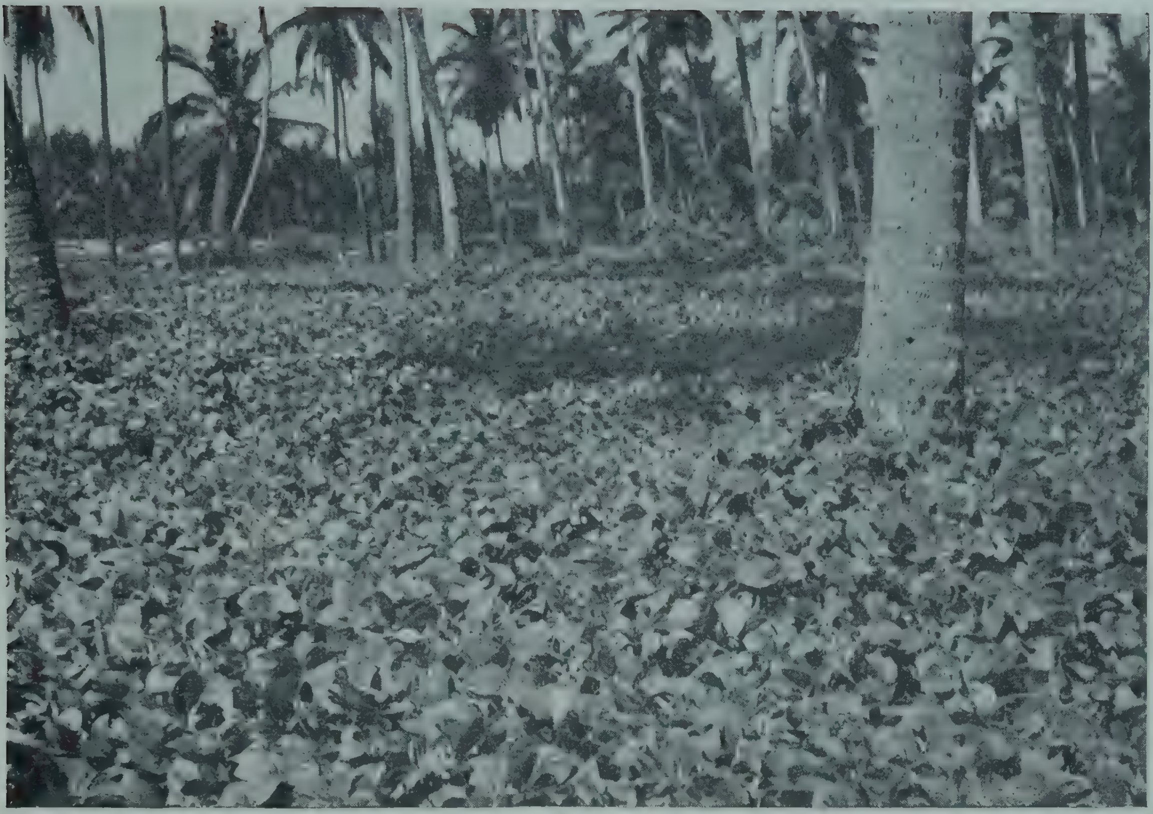

Fig. 70. Cover crop (*Calopogonium mucunoides*)

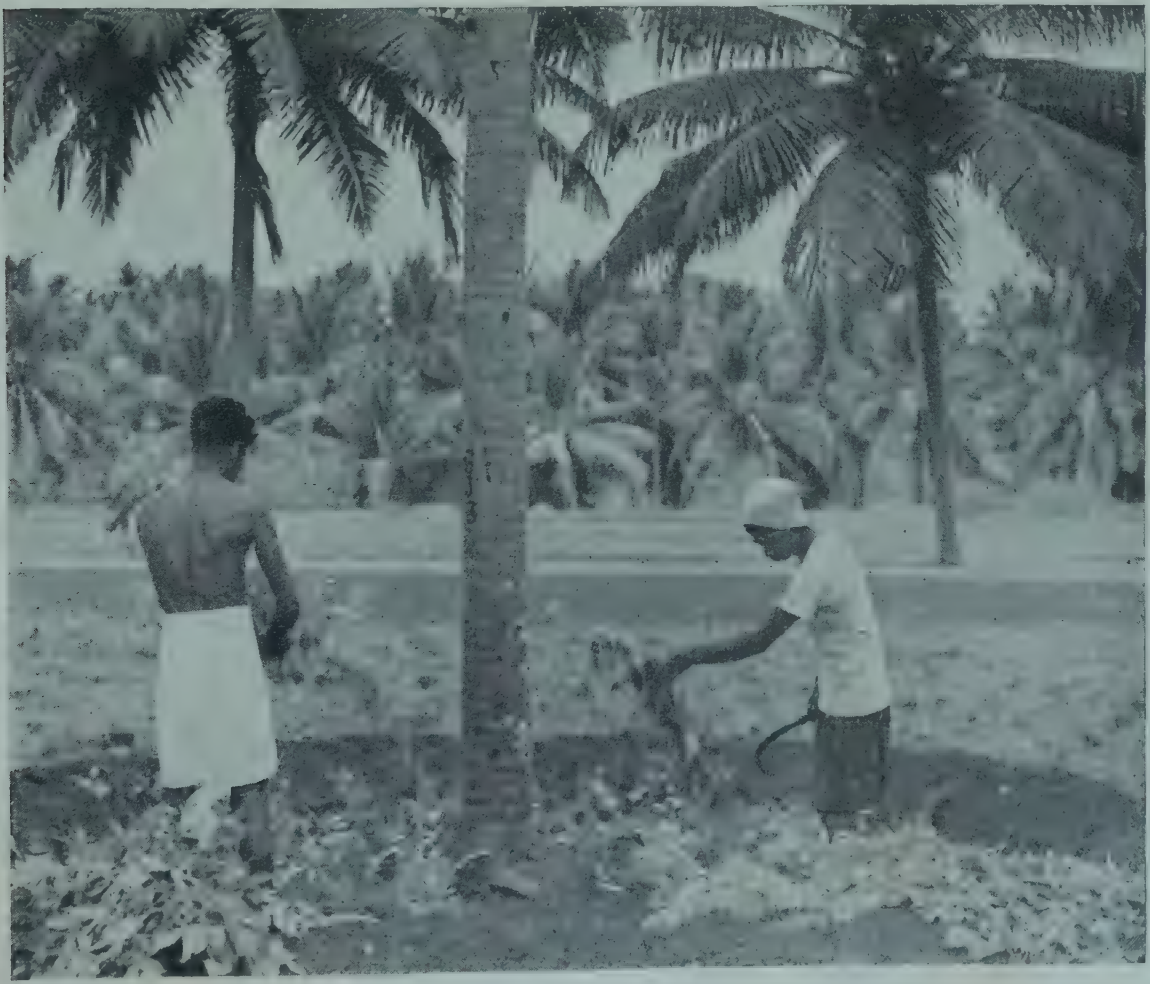

Fig. 71. Applying manures in basins

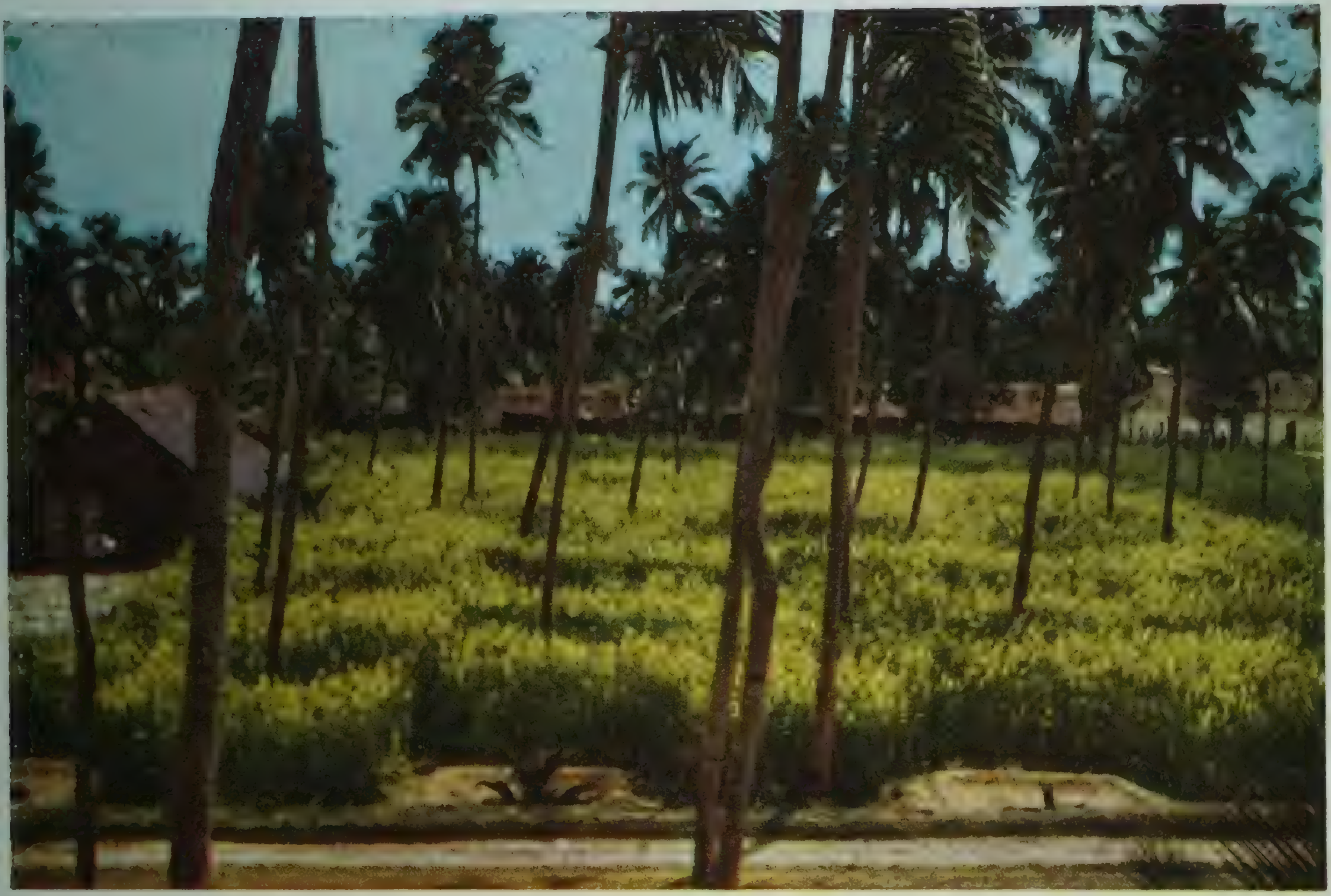

Fig. 72. Sunn-hemp, a green manure

Green manuring consists in turning into the soil green plant material grown *in situ* or brought from outside. Some of the functions of green manuring are the following :—

(1) Maintenance of the humus content of the soil. Humus resulting from the decay of green manures improves the physical properties of the soil such as absorptive capacity, aeration, drainage and granulation.

(2) Stimulates biological activity in the soil.

(3) Exerts a conserving influence on soil nutrients and brings them upwards from the sub-soil and deposits them within the root zone.

(4) Increases the availability of the inorganic constituents of the soil.

In the coconut areas of India, the growers are in the habit of applying green leaves if available to the coconut palms. Where soil and other climatic conditions permit, crops such as cowpea (*Vigna catjang*), sunn-hemp (*Crotalaria juncea*) (Fig. **72**), *Dhaincha* (*Sesbania aculeata*) and *Pillipesara* (*Phaseolus trilobus*) are sometimes found grown for green manuring purposes. It has, however, been demonstrated by extensive field tests that *Crotalaria striata* is the most suitable green manure crop for growing *in situ* and incorporating in coconut gardens, specially of the West Coast of India, in view of its following favourable features (John, 1952; Rao, 1953).

(1) It comes up well in all types of soils on which coconut is being grown in India.

(2) It tolerates shade of the trees and is able to stand up to the heavy rains received in the tract.

(3) It grows quickly and gives good tonnage of green matter in about 3 to 4 months time.

(4) The leaf material is rich in nitrogen (2·2 per cent) and decomposes very readily and rapidly in the soil.

(5) It is not eaten by cattle and is fairly free from the attack of serious pests or diseases.

(6) It produces seeds in abundance. Very good crops can be obtained from self-sown seeds.

The practice of growing crops for green manuring is in vogue in other countries also. In the Philippines, Lima bean (*Phaseolus lunatus*), *Tephrosia candida* and *Tephrosia vogelle* are being used. In Puerto Rico, a species of *Mucuna* is reported to be in use. In Malaya, crops such as *Centrosema pubescens, Calopogonium mucunoides, Dolichos hosei, Pueraria phaseoloides, Tephrosia candida, Tephrosia vogelle* and *Crotalaria anagyroides* are being grown.

In gardens where growing of green manure crops *in situ* is not possible, growers can plant quick growing green manure bushes such as *Gliricidia maculata, Tephrosia candida, Indigofera teysmanni, Crotalaria anagyroides*, etc., on the borders of their plantations. In two to three years' time, sufficient loppings of green leaves can be got for application to the soil. The method of growing and using *Gliricidia maculata* has been described by Krishna Marar (1956).

Pandalai *et al.* (1954) have given detailed analyses of the nutrient contents of a few green manure plants suitable for coconut plantations and have shown that they contain both macro and micro nutrients. To get the maximum benefit out of these, the time of cutting and incorporation are important. Crop grown *in situ* is best incorporated at the flowering time. If it is allowed to become woody, then its value will diminish. The green material should be incorporated when there is sufficient moisture in the soil.

Though green manuring is largely advocated and is also practised, no data appear to be available in literature regarding its relative merits in the manuring of coconut as compared to other forms of manuring. According to Tammes (1938), green manuring never gave increased yields in South Celebes.

(*h*) Soil amendments and ameliorants

The practice of applying materials such as lime and common salt to the coconut trees is a long standing one in many coconut growing countries of the world. Actual experimental evidence regarding their practical utility under field conditions is yet meagre. Lime is supposed to correct soil acidity but at the quantities ordinarily applied, it cannot have any significant influence on soil reaction. It can, however, exert a beneficial effect by counteracting the toxic effect of high content of soluble aluminium salts as has been observed by Wilshaw (1941). Salgado (1947*b*) has examined the claims advanced for the application of lime and common salt based on their known chemical and physical effects on the soil and has concluded that at the present state of knowledge, these materials cannot be recommended as manures for the coconut. In view of their widespread use by the growers, more detailed investigations appear to be necessary.

There is a practice in the coastal and backwater areas in India to apply silt and clay to coconut gardens in sandy loam and sandy soils and silt and river sand to plantations in reclaimed clayey soils. The reported beneficial effects of these practices may be due to their effect on soil structure and also due to the nutrients they contain (Sankarasubramoney *et al.*, 1952). The use of filter press mud from sugar factories as a soil ameliorant is indicated by Pandalai *et al.* (1953).

(*i*) Burial of husks

Husks are an important bye-product of the coconut industry. In certain coconut tracts of India such as Travancore-Cochin, where good retting facilities exist, husks are being used on a very large-scale for processing into fibre. Where husks are not in much demand and can be had cheap or where the disposal of accumulated husks is really a problem such as in Ceylon, they can with advantage be buried in between rows of trees in the plantations. This is being done on a systematic scale by progressive estate owners in Ceylon. *Leaflet* No. 5 (1953) of the Coconut Research Institute of Ceylon contains among others, detailed instructions regarding the different methods of burying husks in coconut plantations.

Field trials carried out at some of the coconut research stations in India have shown conclusively that burying of husks at the rate of 1,000 husks per tree in linear trenches 2 m wide and 0·4 m deep is a useful method of improving the coconut gardens under rainfed conditions. As a result of one operation, a significant increase in yield was noted from the third year onwards and the beneficial effect lasted for a period of about five years.

The improvement observed on account of husk burying may be due to better conservation of water and the supply of potash nutrient. Husks can absorb and retain about six times their weight of water and this property can prove extremely valuable in times of drought. The potash present in the husk to some extent is in a soluble form and is, therefore, easily available to the roots when husks are buried in the soil. The spongy structure of the husks also provides a good medium for the vigorous growth of the root system.

The importance of the husk as a source of potash depends upon the source of the husk and how it is stored (Salgado, 1936). The potash content of the husk is correlated with the potash status of the soil. Husk from trees growing on gravelly soil is much lower in quality than that from trees growing on sandy loam. Over 50 per cent of the potash salts in the husk was found to have been lost by leaching after immersion in water for nearly two months. This indicates that to preserve the manurial value, the husk intended for burying should be stored under cover without exposure to rains.

Husks should not be buried in coconut gardens subject to water stagnation as it will only serve to worsen the situation.

INTERCROPPING

In coconut gardens where the palms are planted 7·5 m to 9 m apart the interspaces might appear to offer opportunities for raising other crops, annuals or perennials, as a source of additional income to the grower. In fact, a variety of crops depending upon the soil and climatic conditions and local demand are being grown in the gardens of small growers. In the early stages of the plantation, when the seedlings are still young and the ground is unshaded, there is no harm in raising such crops, provided care is taken to see that the subsidiary crops are well manured and that they are not grown to the very base of the palms. It is better to leave uncropped about 2 m all round the base of the palms and keep the area free of weeds by repeated cultivation. Manures for the young palms can be applied in this area and incorporated.

The crops commonly cultivated in young plantations in India are: tapioca (*Manihot utilissima*) (Fig. 73), sweet potato (*Ipomoea batatas*) (Fig. 74), banana (*Musa* sp.), yams (*Amorphophallus companulatus*), colocasia (*Colocasia antiquorum*), turmeric (*Curcuma longa*), ginger (*Zingiber officinale*), paddy (*Oryza sativa*), ragi (*Eleusine coracana*), jowar (*Sorghum durra*), sugarcane (*Saccharum officinarum*) and crops like horse gram (*Dolichos biflorus*), cow gram (*Vigna catjang*), green gram (*Phaseolus mungo*), pine-apple (*Ananas sativus*) and different kinds of vegetables. In the Philippines, Manila hemp (*Musa textilis*), paddy and maize (*Zea mays*) are reported to be grown.

The subsidiary crops can and are being raised in the adult plantations also, but, because of the shade of the canopy of the overhanging leaves, the range of crops that can be grown is limited and the yield that can be obtained will also be much less than in the open. Trials carried out in the Coconut Research Station, Pilicode on the West Coast of India, have shown, that, the subsidiary crops with proper attention to manuring can be grown without in any way affecting the yield of the coconut palms. In fact, subsidiary crops raised with adequate manuring and irrigation have been found to considerably benefit the coconut palms. The results can certainly be adverse if crops which are heavy potash feeders such as tapioca are grown without manuring continuously for long periods. In Ceylon, Napier grass (*Pennisetum purpureum*) grown without manuring was found to depress the yields of the coconut (Salgado, 1947*a*). In Brazil, Manihot (cassava) is recommended to be grown in coconut plantations because of the reported favourable effects on soil permeability and moisture conservation.

The practice of growing trees of a perennial nature along with the coconut is also widely prevalent in the coconut areas particularly in the holdings of small growers. Mango (*Mangifera indica*), jack (*Artocarpus integrifolia*), arecanut (*Areca catechu*), bread fruit (*Artocarpus incisa*) and other trees which satisfy some of the needs of the growers are found grown in the coconut gardens on the West Coast of India. Rubber and coffee (*Coffea* sp.) are also sometimes found grown. In Malaya, coffee, mangosteen (*Garcinia mangostana*), rambutan (*Nephelium lappaceum*) and chikku (*Achras sapota*) are recommended. In Zanzibar and Seychelles, clove (*Eugenia caryophyllata*) is being raised. In some coconut growing countries cocoa (*Theobroma cacao*) is also being interplanted with coconut.

No definite experimental evidence as to the effects of growing perennial crop plants mixed with coconuts has yet been found reported but a few workers have given the results of their observations. Thus Brown (1911) and Smith (1932) say that rubber trees should on no account be interplanted with coconuts as they cannot possibly thrive well together. Diseases (*Phytophthora palmivora* and *Fomes lignosus*) of rubber can spread to coconut palms and cause havoc. Bunting (1930) cites a glaring instance from Ceylon of the bad effects of interplanting a coconut garden with tea and fruit trees. The average yield of the coconut palms which was only 18 nuts shot up to 62 nuts per palm when the intercrops were removed. An interesting case where interplanting coconut with other trees proved indirectly beneficial to the coconut has been reported by Sethi (1954) from East Africa. Cashew, citrus and mango trees interplanted with coconut are reported to have favoured the multiplication of ' Majimono ' ants, the natural enemy of the Coreid bug, which causes the immature nut-fall in coconuts.

Intercropping of perennial plants in gardens where palms are planted adopting the usual spacing is not to be encouraged as such cropping will result in intense competition and adversely affect the growth and performance of both the crops. Such intercropping will further make it rather difficult to give proper attention to the different kinds of trees according to their special and individual requirements. If, however, it is desired to raise other trees also, to diversify the sources of income of the grower, two ways are open. One is to plant the trees in alternate rows giving sufficiently wide spacing to reduce mutual interference of one over the other and the second is to assign different portions of the available area among the different crops. The latter is better than the former.

MIXED HUSBANDRY

Of late, considerable interest is being evinced in Ceylon in establishing pastures in coconut gardens with a view to maintaining livestock as a subsidiary source of income to the coconut grower. This mixed husbandry involves an extended study of the inter-relationships of coconut and cattle in order to evolve a pattern that will enable the palms and cattle to be maintained for long periods without deterioration. A number of problems require investigation, for example, evolving suitable grass and legume forage plants that grow in the shade of the coconut, working out proper pasture management practices, determining the correct intensity of grazing and the carrying capacity of gardens, etc. An integrated study of the problems involved is in progress at the Coconut Research Institute, Ceylon (Goonasekara, 1951, 1953*a*, *b*, *c*). According to Rajapakse (1950), maintaining cattle, particularly buffaloes, on estates can also be very effective in controlling the obnoxious weed ' illuk ' found in coconut plantations.

MECHANISATION

The coconut being largely a crop raised by small holders, the opportunities for any large scale mechanisation of the operations ordinarily done on coconut estates are few and far between. However, where estates are large and cover many hundreds of acres, mechanisation may be of distinct advantage particularly in countries where labour shortage may hinder the carrying out of essential operations at the proper time. This subject has been dealt with in its different aspects by De Silva (1951), Senanayake (1952) and Wijewardene (1953, 1954). The last mentioned author has given a list of operations on coconut estates that can be mechanised and has adduced facts and figures to show that on a 200-acre estate, mechanisation can certainly be paying. On the other hand, in the sticky coastal clay soils of Malaya, mechanised cultivation is reported to have had a depressing effect on coconut palms.

DISPOSAL OF MAJOR AND MINOR PRODUCTS

To get the highest possible income from a coconut plantation it is not enough if maximum production at minimum cost is aimed at. It is equally necessary to see that the products are disposed off in the most profitable manner.

Coconut is the most valued product of the palm. It can be disposed off in a variety of ways depending upon the facilities available. The most common method of disposal in India is to sell nuts as such, whereas in other countries, transaction usually takes place as copra. Copra can further be milled and sold as oil and cake. Fresh nuts can also be processed into ' desiccated ' coconut for disposal. The relative advantage of one method over the others will depend upon the prevailing market rates for the different products and the cost of producing them. Abeywardana (1954), has shown how, with a knowledge of the outturn and cost of manufacture of copra, one can with the help of charts come to a quick decision whether selling nuts or copra is more profitable at given market rates.

It is true that it may be beyond the capacity of any individual coconut grower, whatever his standing and resources may be, to provide the necessary facilities for the conversion of nuts into the different forms mentioned. However, these arrangements can easily be made by the growers on a co-operative basis. A good example of such co-operative endeavour is provided by the Sandalanka Coconut Producers' Co-operative Society Ltd. of Ceylon. Direct dealings of the producers with the ultimate consumer without any intermediaries will also help the former to realise maximum price for their products.

Besides nuts, minor products such as dry leaves, midribs, spathes, flower stalks, etc., will also be available in coconut gardens in appreciable quantities. Krishna Marar (1955) has shown how a planned programme of disposal of these will serve to augment the income from the plantation.

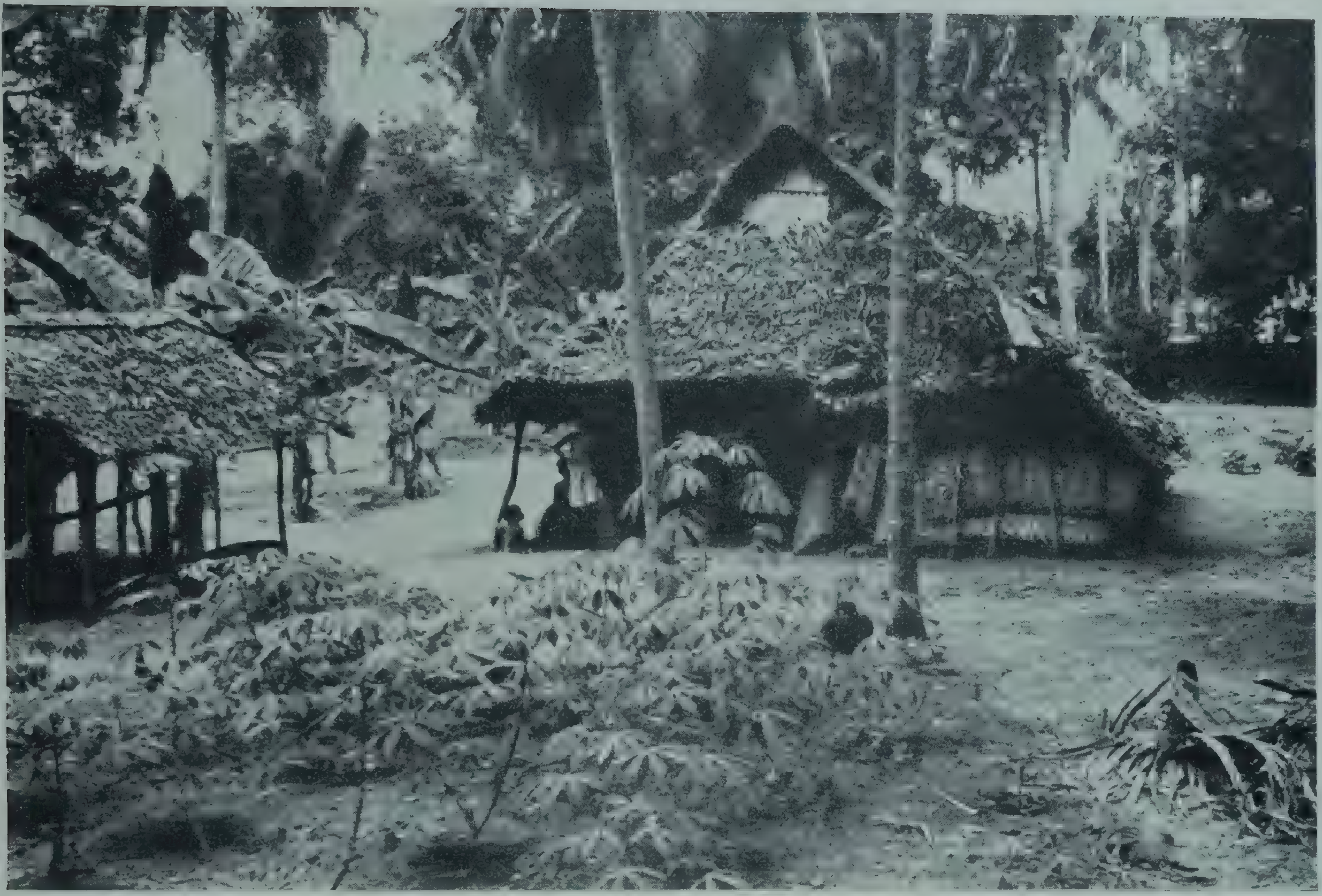

Fig. 73. Inter cropping (tapioca)

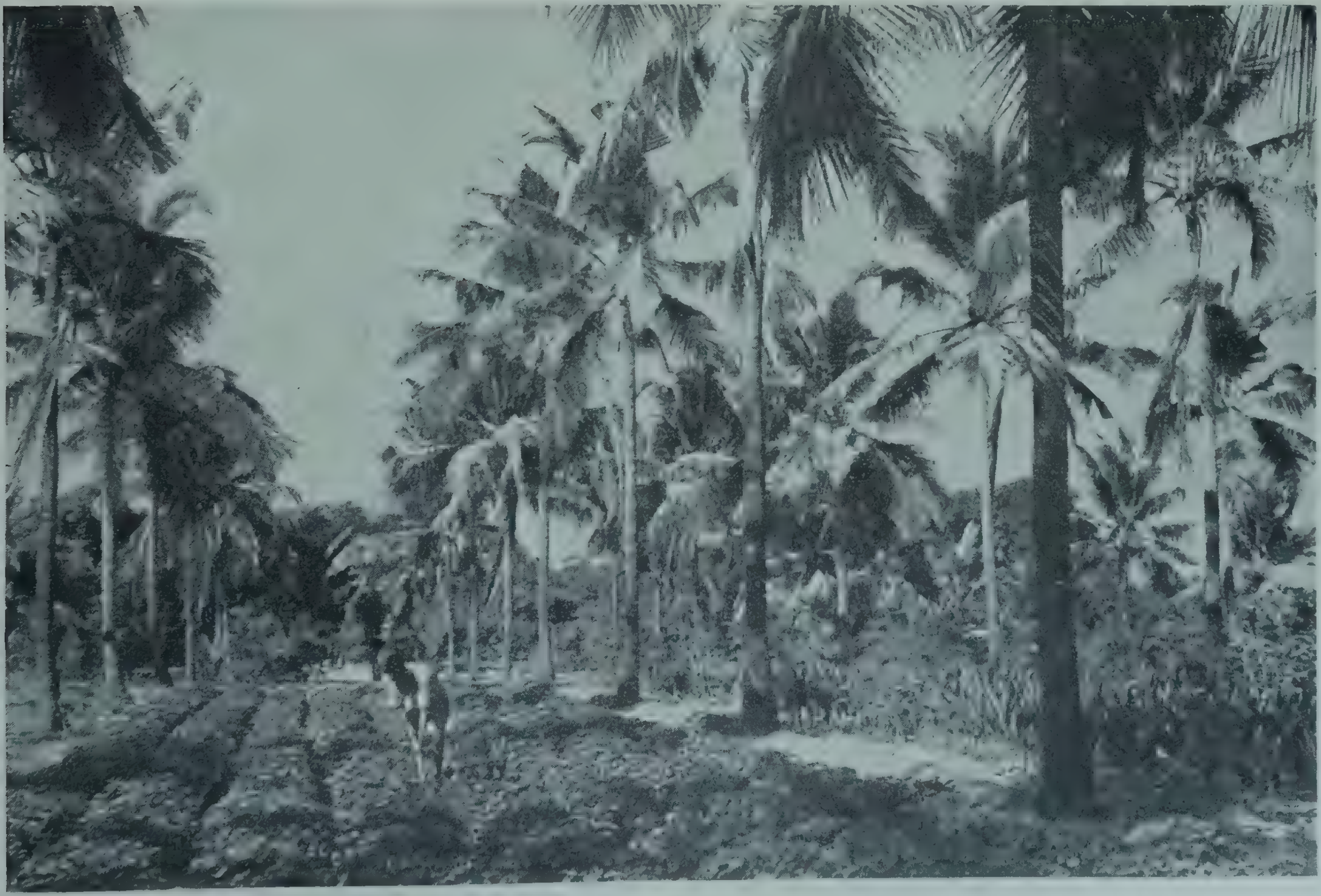

Fig. 74. Inter cropping (sweet potato)

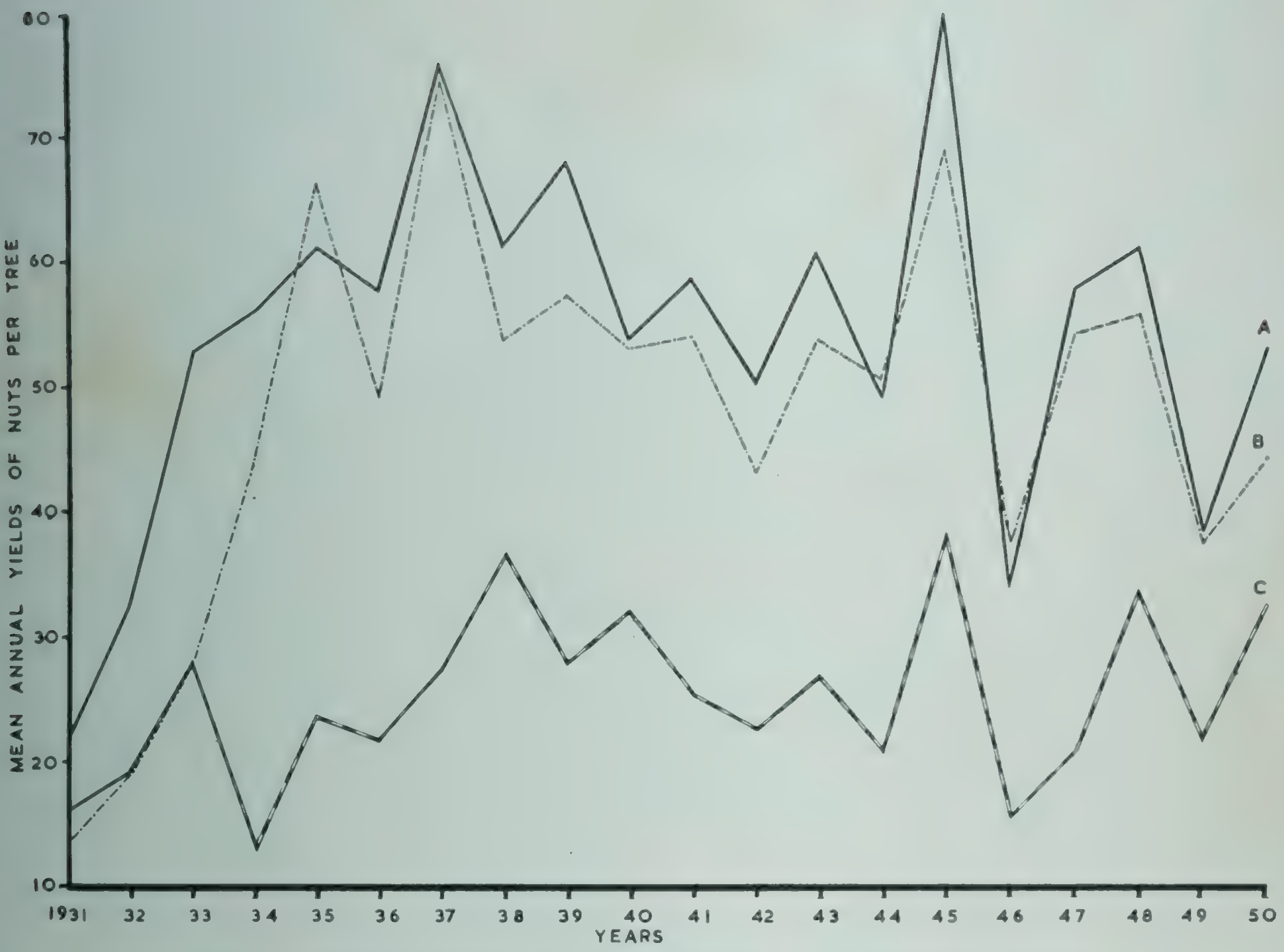

Fig. 75. Pattern of bearing in palms under good management and neglect

A. Regularly cultivated and manured.
B. Regularly cultivated but not manured.
C. Neither cultivated nor manured.

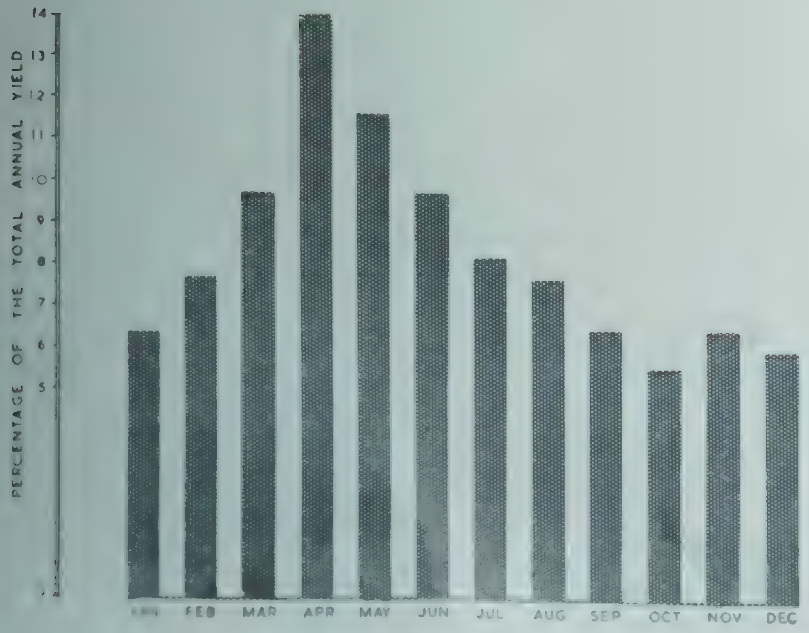

Fig. 76. Monthly variation in yield

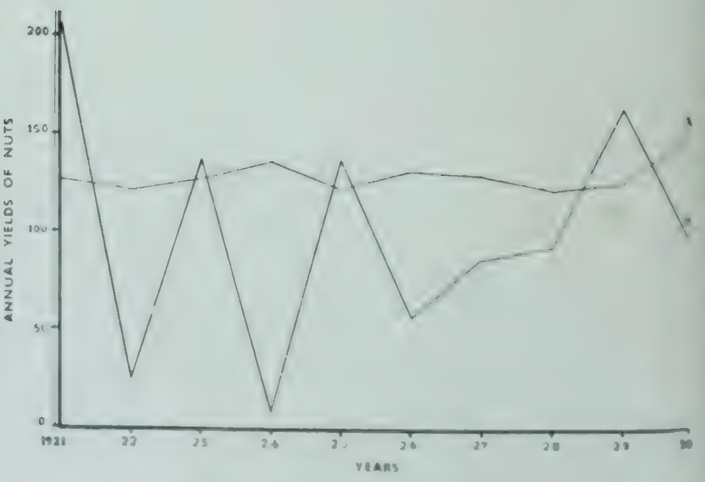

Fig. 77. Pattern of bearing in regular (A) and alternate (B) bearers

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CHAPTER XI

YIELD

The yield of the coconut palm may be expressed in terms of number of nuts, weight of copra or weight of oil, that can be obtained from one tree or an acre of coconut plantation. In the latter case, the stand of palms will be an important factor to be reckoned with. In India, the most important criterion is the number of nuts, while in other coconut growing countries, such as Ceylon, Philippines, Malaya, etc. greater emphasis is laid on the yield in terms of copra outturn. Since the outturn of copra is highly correlated with the yield of nuts, the latter can under similar conditions be taken to indicate the yield in terms of copra also. In this chapter, wherever yield is mentioned, it is with reference to the number of nuts and not to copra or oil.

A number of factors are associated with the yield of the coconut. They are classified by Dwyer (1938) as follows :—

(1) Genetical and inherent characteristics of the trees or palms.

(2) Climatic environment, such as rainfall, temperature, altitude and prevailing winds.

(3) Cultural environment, e.g., manuring, cover-cropping and cultivation.

(4) Soil environment, e.g., chemical, physical and biological characteristics.

(5) Other factors such as the ones produced by pests, diseases and changes and effects produced by other flora and fauna.

Many of the factors included above have been independently and exhaustively dealt with in other chapters. The discussion in this chapter is, therefore, proposed to be confined to those aspects which have not been dealt with elsewhere.

AGE OF THE PALMS AND YIELD

The age at which the palms come into bearing and the period for which they will give satisfactory yields are highly variable and are correlated with the soil and climatic conditions, the variety grown, and methods of management. The tall variety of the coconut palms normally begins to bear in 5 to 7 years after planting, while the dwarf variety palms usually begin to fruit in their third or fourth year. The economic bearing period of the tall variety may be 40 to 50 years or more, whereas that of the dwarf variety will not be more than 20 to 25 years. In India, the palm reaches the bearing stage early in the alluvial and red loam soils, while this period gets considerably prolonged in laterite and sandy soil areas with low water table. Again, when the palms are closely planted, they take much more time to commence bearing than when they are planted at an optimum distance. That proper attention to the young palms in the early growth period will make them bear earlier has already been referred to.

Palms which have come to the bearing stage will take another 5 to 6 years to reach the stage of full productivity. In the earlier years, the yields will be poor for the following reasons :—

(1) Fewer number of spadices are produced. Spadices will not be produced regularly in every leaf axil.

(2) Spadices produced may not have any female flowers at all or have only a very small number.

These characters gradually improve with age, resulting in increased yields. This will be clear from the data given in the following table (Patel, 1938).

Table 43.—**Performance of trees at different stages of bearing at the Central Coconut Research Station, Kasaragod**

Serial No.	Palm Characters	YEARS OF BEARING									
		First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	Tenth
1.	Total number of barren axils per tree	2·1	2·4	2·4	1·7	1·0	1·0	0·6	0·7	..	..
2.	Number of spadices without female flowers per tree	3·0	2·2	2·0	1·3	1·1	0·2	0·2	0·2	..	..
3.	Number of fertile spadices per tree ..	3·7	6·5	7·5	8·7	10·0	10·5	10·6	10·6	12·3	13·0
4.	Number of female flowers per fertile spadix..	12·0	13·0	14·0	17·0	19·0	15·0	18·0	23·0	27·0	33·0
5.	Total number of spadices per tree	7·2	8·8	10·2	10·7	11·5	11·0	12·1	12·2	12·3	14·5
6.	Number of nuts per annum..	9	17	17	27	40	49	49	50	65	80
7.	Setting percentage ..	20·0	20·0	18·0	18·9	21·0	31·1	25·1	20·0	20·0	20·0

Smith (1932) reports that in the alluvial soils of Malaya, full mature yields are obtained from the 12th year after planting, though bearing starts about the 8th year. In the Philippines also, the palms are reported to commence bearing in 5 to 6 years after planting. In a well managed coconut garden in Ceylon, full bearing appears to have been reached in the 8th year itself. Dwyer (1938) reports that in New Guinea and Malaya, in certain types of soil and under particular climatic conditions, palms coming into the stage of maximum production have been noticed to suffer a physiological setback affecting the production for a period of two years.

In a coconut plantation, all the palms do not come to the bearing stage at the same time. Even under the best conditions of management, some bear very early while others bear very late. The number of palms that came into bearing in different years after transplanting in a group of 180 trees in an estate in Ceylon are shown below (Cooke, 1954).

Year after transplanting	*Number that came into bearing*
6	1
7	11
8	29
9	34
10	42
11	18
12	11
13	6
14	9

After 14 years, 10 per cent of the palms had still not commenced bearing. In view of this fact, full bearing from a plantation can be expected only 20 to 25 years after its establishment.

The period taken for first bearing is correlated with the yielding potentiality of the tree. Early bearers yield more than late bearers. The following data obtained at the Coconut Research Station, Nileshwar-II (India) (Patel, 1936) are reproduced here in support of the above. The trees were of the same age and received the same treatment.

Table 44.—Progressive yield in relation to flowering and age

Year of bearing	Average yield per tree according to age in years at first flowering						Average yield per tree per annum
	7	*8*	*9*	*10*	*11*	*12*	
First year	3·0	4·2	2·1	1·5	2·1	2·4	2·6
Second year	13·8	10·7	7·5	10·0	4·9	3·8	8·5
Third year	16·9	12·9	12·2	12·6	7·2	4·6	11·1
Fourth year	24·7	19·8	13·7	12·5	4·2	1·0	12·7
Fifth year	25·9	21·0	14·0	10·2	2·6	..	14·7
Sixth year	25·6	21·4	10·1	7·5	..	..	16·2
Seventh year	20·2	16·2	5·4	..	..	..	13·9
Eighth year	14·6	10·2	..	..	..	..	12·4

After reaching the full bearing stage, the yields will remain steady for 40 to 50 years or more, provided the soil conditions are maintained at a satisfactory level. After the peak period is over, the yields will begin to decline with the onset of old age.

VARIATION IN YIELD IN THE DIFFERENT COUNTRIES

The yield of ripe coconuts obtained in the different coconut growing countries of the world is found to vary. The differences may be due to the combined effect of the variety grown and climatic and soil conditions. The approximate average yields reported to be obtained in some of the countries are given below :—

Philippines	2,850 nuts per acre per annum.
India	2,000 —do—
Ceylon	1,800 —do—
Malaya	1,400 —do—
British Solomon Islands	1,200 —do—
British Guiana	15 nuts per tree per annum.
New Guinea	40 —do—

VARIATION IN YIELD WITHIN A COUNTRY

Within the same country, considerable variations in yield are noted from region to region, as can be seen from the data furnished below for India (Agricultural Marketing Adviser, 1944) and Ceylon (Cooke *et al.*, 1951).

States in India	*Nuts per acre per annum*
Madras	2,100
Travancore	1,950
Mysore	2,000
Cochin	1,860
Orissa	1,760
Bombay	1,896
Assam	1,080

VARIATION IN YIELD WITHIN A COUNTRY—*(Contd.)*.

Districts in Ceylon	*Nuts per acre per annum*
Maravila	4,000
Chilaw	3,500
Negombo	2,500
Kurunegela	2,000
Colombo	1,500
Galle	1,500
Puttalam	1,000

These differences are again to be ascribed to the differences in soil and climatic conditions.

ANNUAL VARIATION IN YIELD

In the coconut, considerable variations in annual yield are found to occur from year to year, even in gardens receiving uniform treatments right through. The variation is more in a neglected garden and less in gardens under good management. This can be seen from the results obtained at the Central Coconut Research Station, Kasaragod, during a 20-year-period and summarised below (Fig. **75**).

	Coefficient of variation (per cent)
Neglected plot	72·8
Regularly cultivated and manured plot	14·6

Jack (1932) has reported that annual variation in the production of nuts per palm in Malaya is 13·5 per cent of the mean production. Analysis of the yield data of 14 years of the NPK manurial experiment at Bandirippuwa Estate in Ceylon showed that, one-third of the total variation was due to season (Coconut Research Scheme, Ceylon, 1951).

The yields are found to fluctuate from year to year without any regularity, though years when heavy yields are obtained are found to be followed immediately by lean years. This must clearly be attributed to weather conditions. What weather factor or factors influence yields are not clear. However, rainfall and its distribution are considered to be the most important. A number of correlations between annual yields and rainfall for different periods have been worked out for the conditions obtaining at the Central Coconut Research Station, Kasaragod (India) (Patel, 1938). Though the data are admittedly insufficient to permit any definite conclusions to be drawn, the indication obtained was that the yield in any particular year is influenced by January to April rains for two years previous to it, together with the rains received in January to April of the year. Park (1934) found that severe drought experienced in Puttalam (Ceylon) affected the yield of nuts for a period of about two years, with the maximum effect at about 13 months after the conclusion of the drought. Shepherd's study in Trinidad (cited by Patel, 1938) has revealed a positive and significant correlation between rainfall over a six-month-period and the size of the nut one year later. In Malaya, the rainfall in the first three months when the nuts are forming, is reported to determine what the crop will be a year later (Cooke, 1953).

MONTHLY VARIATIONS IN YIELD

It has already been mentioned that from regular bearing palms, a bunch of nuts can be harvested almost every month. Monthly records of harvest and yield of nuts are being maintained for a series of years at the Central Coconut Research Station, Kasaragod, which has over 6,000 trees in bearing. From these data, the percentage of the total yields obtained in each of the different months of the year was calculated and is given below. This is also represented in the histogram given in Fig. **76**.

Table 45.—Monthly variations in yield—Central Coconut Research Station, Kasaragod

Month of the year	Percentage of the total yield
January	6·4
February	7·7
March	9·8
April	14·1
May	11·7
June	9·8
July	8·2
August	7·7
September	6·5
October	5·6
November	6·5
December	6·0

The month of April has the maximum share of production and the first six months of the year account for about 60 per cent of the annual yield. This pattern of production is seen to persist year after year with minor variations. The larger harvests are due to the combined effects of larger number of trees giving yields, larger number of bunches harvested and larger number of nuts per bunch.

Similar periodicity in bearing within a year is also found in the other important coconut producing areas in India. Thus in Travancore, 75 per cent of the total annual yields is reported to be obtained between January and July and in Cochin, more than 90 per cent during the same period. In Mysore, harvests obtained during the period July to October are reported to be heavier than in the other months.

In other countries also, variation in production within a year has been recorded. In Ceylon, where six picks are done in the year, the 3rd and 4th picks done between May and August, account for a much larger share of the total crop than the others. The data in respect of Bandirippuwa and Ratmalagara Estates are presented below :—

Table 46.—Variation in yield among the different picks in a year

Pick No.	Months	Percentage of the annual crop	
		Bandirippuwa	Ratmalagara
I	January & February	11·8	13·2
II	March & April	19·4	15·8
III	May & June	23·2	19·6
IV	July & August	20·9	21·1
V	September & October	13·8	17·5
VI	November & December	10·9	12·8
	Total	100·0	100·0

In Malaya, the smallest harvests are reported to be obtained in the wet season, whereas in the Philippines the heaviest production is obtained during rainy months.

INHERENT VARIATIONS IN YIELD

The population of trees in any coconut plantation is generally found to consist of trees of different yield capacities. Though a continuous gradation of trees from poor yielders to heavy bearers can be seen, it is possible to roughly classify them as poor, medium and heavy bearers. These will be found to occupy the same relative position in spite of the fact that they are found to respond differentially to better plantation management. The results of an investigation carried out in a plantation consisting of about 1,400 trees are summarised below :—

Table 47.—Proportion of trees of different yield groups and yield accounted for by them

Yield group (mean annual yield)	Percentage of trees falling in the group	Percentage of total yield accounted for by the group
Poor (40 nuts and below)	32·0	17·3
Medium (41 to 80 nuts)	59·4	66·9
High (81 and above)	8·6	15·8
	100·0	100·0

It is seen that a smaller percentage of the trees accounts for a relatively larger percentage of the yield. Thus high yielders which formed only 8·6 per cent of the trees gave 15·8 per cent of the total crop, while poor yielders which formed 32·0 per cent of the population had only a share of 17·3 per cent. Similar observations have been made in other countries also. Murray (1950), analysing the yield records of 600 trees of an estate in Trinidad found that 9 per cent of the trees comprising the best yielders gave 21 per cent of the total crop, while 19 per cent comprising the worst trees yielded only 3 per cent. Jack (1925), in Malaya concluded from a study of yields of 473 trees that 19 per cent of the palms was unprofitable and 13 per cent of the palms produced 22 per cent of the crop. Analysis of the yields of 296 palms of Bandirippuwa Estate (Ceylon) in 1949 showed that 70 per cent of the total crop was derived from 55 per cent of the population and that nearly half the number of palms accounted for only 30 per cent of the total harvest. It was also found that if 10 per cent of the palms yielding less than 30 nuts were removed, only 4 per cent of the crop would be lost (Coconut Research Scheme, Ceylon, 1951). Cramer (private communication) in his studies of yields from a plantation in Java found that 50 per cent (poorest) trees produced 33·4 per cent of the crop while the other half composed of best yielders yielded 66·6 per cent.

Patel (1938) has given the results of a detailed study of the characters associated with yield in a set of heavy, medium, and poor bearers growing in one compact block and receiving identical treatment at the Central Coconut Research Station, Kasaragod. The data are summarised below :—

Table 48.—Characters associated with yield in trees of different yield groups

Character (Mean value)	Heavy bearers (yielding an average of over 80 nuts per year)	Medium bearers (35 to 80 nuts per year)	Poor bearers (below 35 nuts per year)
Annual yield	99·8	58·8	25·0
Number of spadices produced per year ..	13·4	12·8	11·4
Number of female flowers produced ..	370	263	135
Setting percentage	26·9	22·3	18·5
Female flowers per bunch	27·6	20·5	11·8
Nuts per bunch	7·4	4·6	2·2

It is seen that the three groups of trees show distinct differences in the characters studied, the values becoming less and less favourable with the decrease in yielding capacity. As far as this particular study is concerned, major differences appear to lie in the number of female flowers produced and the percentage of setting.

REGULAR, IRREGULAR AND ALTERNATE BEARING

In coconut plantations where regular tree-wise yields are maintained for a series of years, it is possible to pick out trees which are alternate bearers, irregular bearers or regular bearers. Alternate bearers yield heavily in alternate years with relatively poor yields in between. In 'irregular' bearers, yields vary from year to year but without conforming to any regular pattern. Regular bearers will show only small fluctuations in yield from year to year. Yield trends of typical palms showing regular and alternate bearing nature are represented graphically in Fig. 77.

The fluctuations in yield observed in the case of alternate bearers are not due to the effects of season, for it is possible to pick out trees which give high and low yields in the same year. High yields are the resultant effect of high female flower production and high setting percentage as can be seen from the data furnished below :—

Table 49.—Some characters of alternate bearing palms

	Average of eight peak yielding years	Average of eight lean yielding years
Yield (no. of ripe nuts)	151·8	48·6
No. of female flowers produced	769·6	376·3
Setting percentage	19·7	12·9

Observations carried out on the performance of the progeny palms derived from regular and irregular bearers at the Coconut Research Station, Pilicode (India), appear to show that the pattern of bearing may not be an inherited character.

YIELD IN RELATION TO AGE OF NUT AT HARVEST

As already reported, different practices are followed in picking nuts the more common one being to harvest the bunch when the nuts are fully or somewhat mature. In some places nuts are allowed to fall from the trees of their own accord while at others where there is heavy demand for tender nuts harvesting is done when the nuts are 6 to 7 months old. Among coconut growers there is a belief that allowing the nuts to fall of their own accord or harvesting nuts when they are not fully mature, are detrimental to yields and that harvesting in the tender nut stage will result in increase in the total crop. According to Simpson (1941), retaining the nuts on the palm after full maturity causes reduction in the yield of nuts for rather more than one year but has no long-standing effect on yields.

Work done in Ceylon (Liyanage, 1955) has shown that harvesting nuts at monthly or bimonthly intervals has no effect on the yield or copra content of nuts. Harvesting of nuts in the tender nut stage (6 months old) was, however, found to result in an increase in the production of immature nuts in high yielding trees (Patel, 1937).

RELATION BETWEEN PALM CHARACTERS AND YIELD

A number of investigations have shown correlations between the yield of nuts and different palm characters. They are given below :—

Table 50.—Correlation of palm characters with yield

Characters correlated with yield	Coefficient of correlation	Authority
Leaf characters :		
Total number of leaves	0·414*	Narayana and John (1942)
Total number of opened leaves	0·45*	Patel (1937)
Number of old leaves	0·45*	–do.–
Number of opened young leaves	0·142	–do.–
Age of leaf	0·38*	–do.–
Rate of production of leaves	—0·19	–do.–
Number of leaflets	—0·161	Patel (1938)
Length of leaflet bearing portion	—0·060	–do.–
Length of petiole	—0·061	–do.–
Total length of leaf including petiole	—0·080	–do.–
Thickness of petiole	0·050	–do.–
Girth of petiole	0·090	–do.–
Area of cross section of the petiole	0·075	–do.–
Number of vascular bundles in the petiole	0·093	–do.–
Area of the surface of attachment of the leaf to the trunk	0·270*	Narayana and John (1942)
Stem characters :		
Length of trunk	0·425*	Patel (1938)
Girth of trunk	0·293*	Narayana and John (1942)
Type of the crown (spherical, compact, loose, etc.) :		
Coefficient of mean square contingency C_1	0·478*	–do.–
Inflorescence characters :		
Number of female flowers	0·204* 0·64*	–do.– Pieris (1934)
Other characters :		
Catalase activity of the tree (oxygen evolved in three minutes)	0·561*	Patel (1938)

* Significant at 5 per cent level.

Of the above, characters such as the number of leaves, length of stem, type of crown, number of female flowers and catalase activity of the trees are found to be of some importance in relation to yield. Tammes (1937) was of the view that yield is not controlled by flower number or pollination but exclusively by nutritional factors, especially water supply. According to Johns (1938), colour, shape and size of nuts are not correlated with yield.

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CHAPTER XII

DISEASES

In spite of its hardy nature, the coconut palm is affected by a number of diseases. These diseases are responsible for enormous economic losses in the different coconut growing countries of the world. Thus, the annual loss caused by the leaf and root (wilt) diseases of coconuts in Travancore-Cochin area (Kerala State) in India has been estimated to exceed ten million rupees by Menon and Nair (1951). In the Philippines, it has been estimated that the loss in nuts in the Bicol region caused by the ravages of the ' Cadang-Cadang ' disease would amount to more than 1·8 million dollars annually (De Leon, 1952).

In plant pathology, the term ' disease ' refers to any disturbance in the normal metabolism of a plant that might either cause its death or reduce its economic value. Depending on the nature of the cause, diseases may be classified as pathogenic or physiogenic. The reaction of the host to the disturbance is known as disease symptom. These symptoms may be manifested externally in many ways, as wilts, rots, die-backs, fruit-falls, leaf-falls, etc. Coconut diseases may be classified as those affecting the bud, the leaf, the stem and the root and systemic diseases like wilts.

DISEASES OF THE BUD

Bud-rot

Rotting of the bud is the ultimate result of all diseases fatal to the coconut ; however, in the specific disease known under the name ' Bud-rot ', the rotting of the bud is due to the primary infection in or near the bud tissue and the earliest symptoms are expressed by the young growing parts in the crown, namely the central shoot. Considerable confusion existed during the early part of this century regarding the nomenclature of this disease. The " West End Bud-rot " of Jamaica (Ashby, 1920), the bud-rot as it occurs in Malaya (Sharples, 1925), Africa (Dowson, 1925), and the British West Indies (Nowell, 1925) were confused with the bud-rot reported by Butler (1906) in India on palmyra and coconut palms. The bud-rot reported by Ashby as the " West End Bud-rot " is now known as the ' Unknown disease ' and is dealt with in detail on pages 225 to 229. The rotting of the bud recorded in Malaya, is mainly, according to Sharples and others, the delayed symptom of lightning strike. Similarly, the investigations on the diseases reported by Dowson and Nowell tend to indicate that their incidence may be traced to unfavourable soil conditions and to infections by nematodes, respectively. In view of these observations and in the light of the investigations carried out in India by Shaw and Sundararaman (1941), the disease now considered as true bud-rot is confined to those infestations where the rotting of the bud is primary and not incidental or secondary.

Occurrence

Diseases affecting the soft tissues of the crown were recorded from Jamaica, Honduras, British Guiana, Cuba, etc. The earliest record known of the occurrence of bud-rot is at Grand Cayman in 1834 (Tucker, 1926). Bud-rot has also been reported from India, Ceylon, East Africa, Central America, Trinidad, Fiji, Philippines, etc., i.e., from almost all areas where coconuts are grown. In India, bud-rot is quite common on the West Coast and the East Coast, where coconuts are grown with *Hevea* (rubber) and palmyra respectively.

Symptoms

The symptoms of the disease as reported by several investigators, consist in the pale colour, bending over, browning and breaking down of the heart leaf (central shoot). Sometimes two or more of the young leaves lose colour and droop before the heart leaf breaks down. The withered heart leaf can be drawn right out by exerting a slight pull. Gradually the leaves in the surrounding whorl lose their green lustre and become dull yellow and brown, indicating that the rotting has further extended. Consequently, the outer leaves and spathes enclosing the central spindle fall off, leaving a ring of fully expanded leaves standing and retaining their colour for many months. Young nuts cease to develop and eventually fall, but, older ones may mature. The softer infected portion will be completely rotten and degenerated to a slimy mass emitting foul smell. The palm succumbs with the death of the only vegetative bud (Fig. *78*).

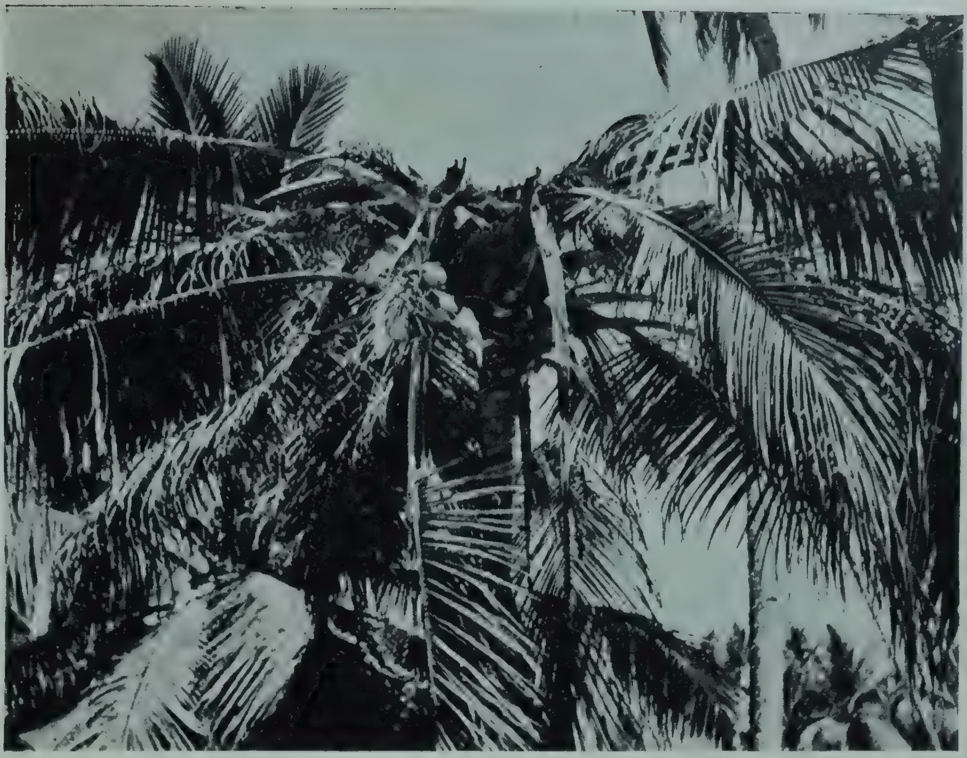


Fig. 78. Coconut palm killed by bud rot

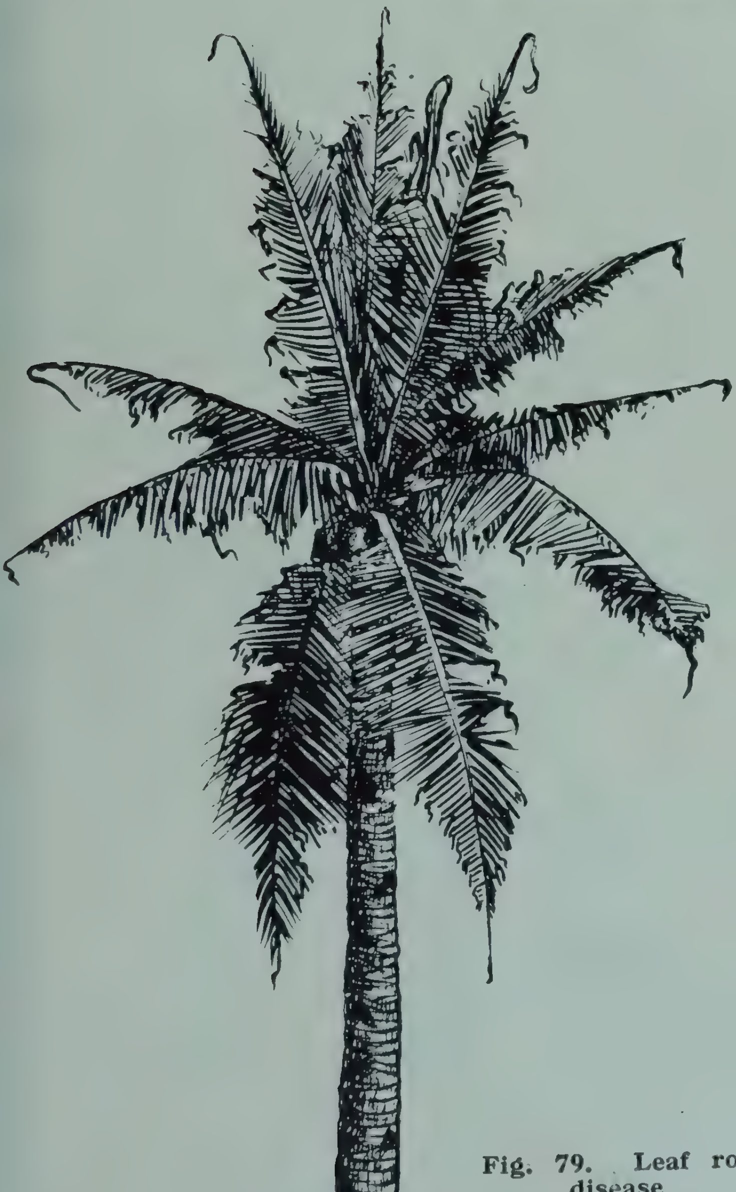


Fig. 79. Leaf rot disease

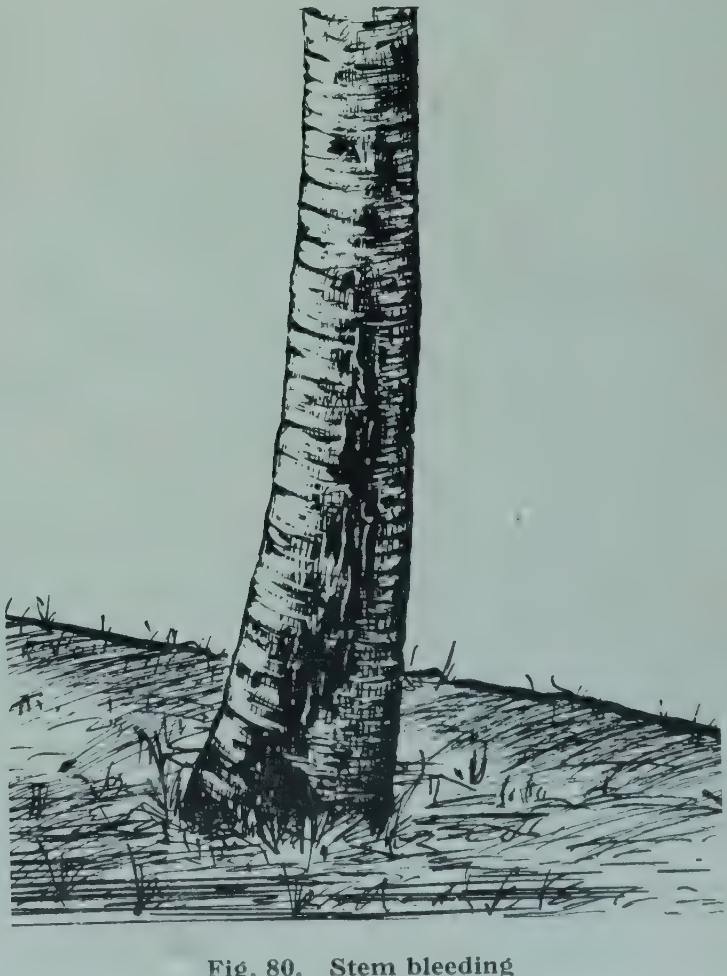


Fig. 80. Stem bleeding

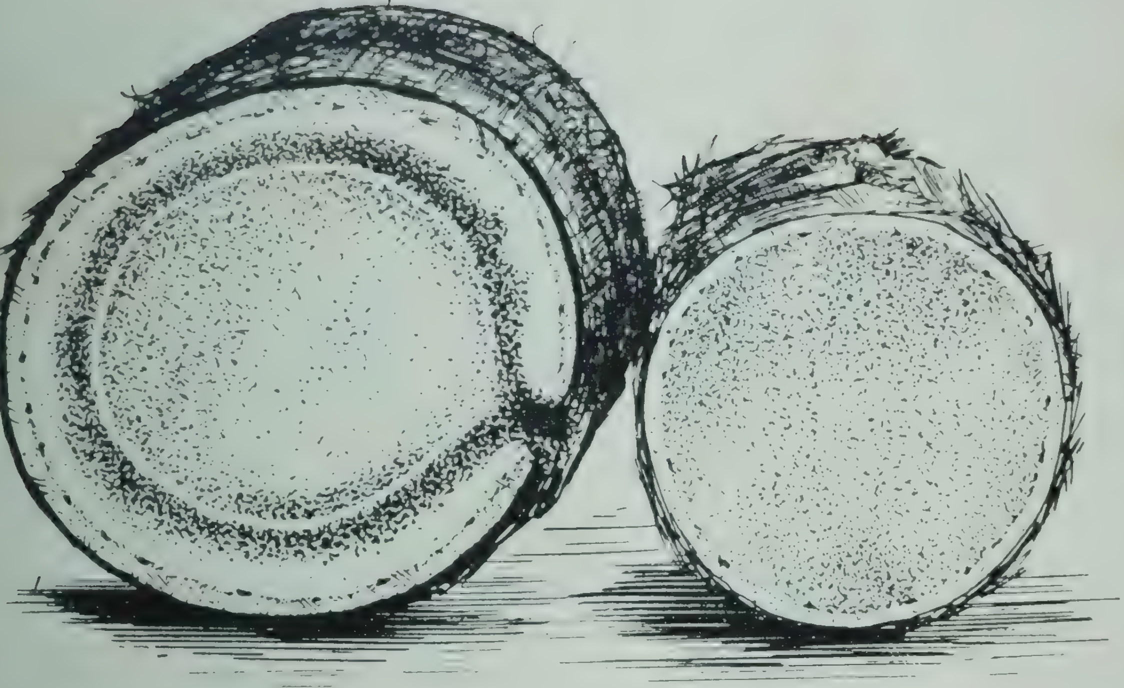


Fig. 81. Sections of stem of tree affected by red ring disease (After Nowell, 1923)

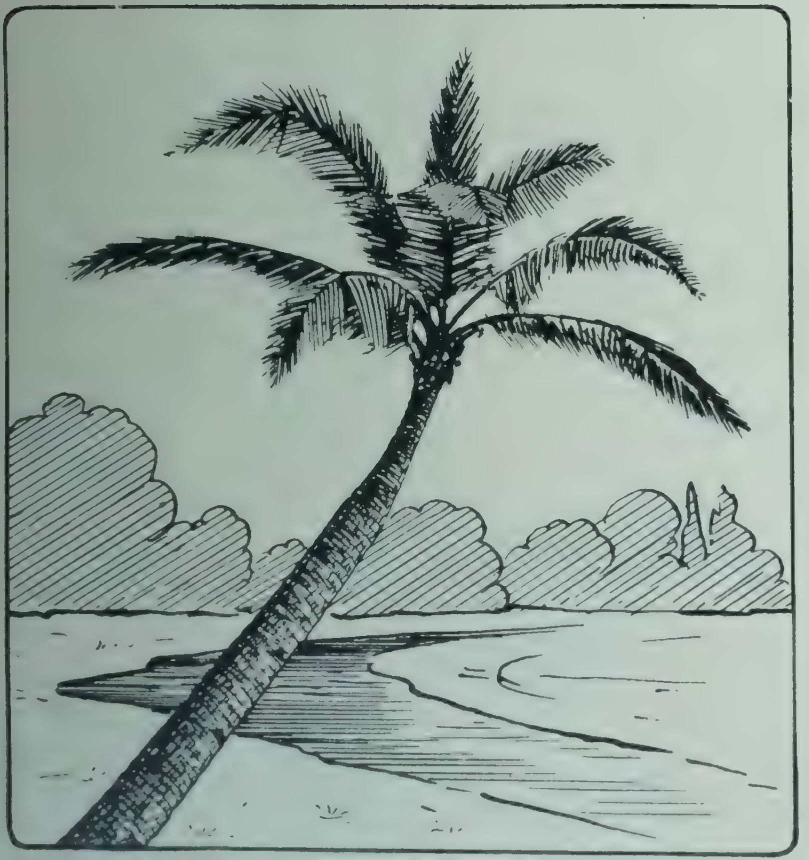


Fig. 82. Tapering stem wilt or pencil point of coconut palm

(After Briton Jones, 1940: *Courtesy:* Bailliere, Tindall and Cox, London)

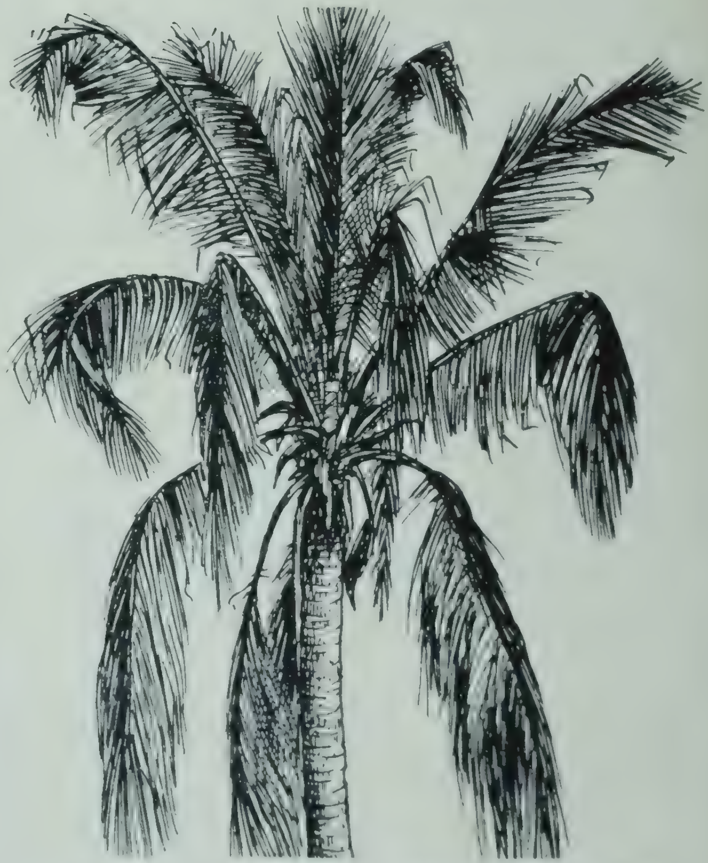


Fig. 83. Bronze leaf wilt disease of coconut palms in Nigeria, early stage of the disease

(*Courtesy:* West African Institute for Oil Palm Research, Nigeria)

At the base of at least one of the young leaves, may be found, brown sunken spots either at the thickest part or near the edge or on the stipule. The spots pierce the affected part and can be followed through the underlying bases into the primordial tissue at the apex of the stem. The spots may be up to 8 cm in diameter on the thick bases or even more on the stipule. They may be yellowish when young, becoming light to dark brown or black later. The rotting is soft in the primordial leaves and the non-fibrous apex of the stem, but sodden and firm when the internal tissues are older and fibrous. If the disease is detected in the early stages, a succession of spots is found to reach the primordial tissue, which wilts and becomes flexible, but firm with a soft-rot starting at the edges. However, generally the non-fibrous apex of the stem is already a pasty mass by the time the disease is noticed. The infection at the leaf base and the death of the heart leaf might be preceded or accompanied by the appearance of rows of lesions on the pinnae. The pinnae often break at these spots with the result that the leaf presents the appearance of ' leaf bitten disease '. Fungal hyphae may be seen as a dense felt on the lesions at the leaf bases, or often form webs in between the spots on the pinnae.

Aetiology

' Bud-rot ' has been the subject of intensive investigations in several countries from the time it was first reported. The causative organism was first suspected to be *Pestalotia palmarum* (Busck, 1902). Later workers favoured the theory of bacterial origin for the disease (Earle, 1903; Petch, 1906; Stockdale, 1907; Fredholm, 1909; Johnston, 1910, 1911), and considered the causal organism as *Bacillus coli* (*Escherichia migula*). Based on the evidence accruing from the investigations of Shaw and Sundararaman (1914), McRae (1923), Tucker (1926), Gadd (1927) and others, this theory was abandoned and it is now generally accepted that the bud-rot of coconut is fungal in origin. In 1906, Butler reported that the bud-rot of palms in India is caused by *Pythium palmivorum,* which was later renamed as *Phytophthora palmivora* Butl. At the Imperial Botanical Conference of 1924, considerable discussions on bud-rot took place, the conclusion drawn from which was that the ' bud-rot ' of coconut is associated with species of *Phytophthora.* In East Africa, the disease is considered to be influenced by the soil conditions (Dowson, 1925; Shepherd, 1927).

In Malaya, Sharples (1925) recognised the possibility of damage to palms by *P. palmivora* but states that other factors like injuries caused by insects and unfavourable soil conditions are also definitely associated with severe attacks of bud-rot. In Jamaica and other islands of the West Indies and in Ceylon, bud-rot due to *Phytophthora* exists (Petch, 1906; Ashby, 1920), but cases suspected to be of bacterial origin are also reported. According to the observations recorded by Tucker, Reinking and others, the bacterium associated with the disease is a saprophyte. Reinking (1919) designated the fungus isolated by him as *P. faberi* Maubl., which causes the pod-rot of cacao and considers it identical to *P. palmivora* Butl. Tucker supported Reinking's view that *P. faberi* or a subspecies causes bud-rot but Ashby (1920) and Gadd (1927) refuted this theory and consider these two organisms as biological variants; Gadd's opinion is substantiated by the fact that *P. faberi* is a common pathogen in Ceylon causing extensive damage to cacao, whereas few cases of bud-rot occur on coconuts growing in the same districts. After reviewing the position, Gadd concluded that bud-rot is caused by *P. palmivora* and that *P. faberi* also can infect coconuts. Ashby (1929) showed that *P. palmivora* Butl. is the same botanical species as *P. faberi* Maubl., and *P. theobromae* Colem. though it exists as a number of distinguishable morphological and pathological strains (Briton Jones, 1940). Thomas *et al.* (1947) working with 25 single hyphal tip isolates of *Phytophthora* occurring on a variety of hosts (including coconut, palmyra and areca palms) have shown that the isolates fall into two groups — the ' plus ' and the ' minus ' strains — and that the members of one group form oospores when paired with any member of the other group. They, therefore, concluded that all the isolates they studied belong to *Phytophthora palmivora* Butl.

Palms of all ages are liable to the disease but it is more rampant in palms between 15 and 45 years old. The period elapsing between the first infection and the withering of the heart leaf depends on a number of factors, the more important of which are relative humidity and the point of infection; it might vary from three to nine months or longer. The fungus might remain dormant in the leaf base during the dry season. Infection might spread vertically or laterally in the crown. Rainfall might aggravate infection when the spotting appears on the pinnae, since the fungus will be washed down into the bud. Young palms in low and moist situations are especially susceptible. Insect attack is considered a predisposing factor for the fungal infection. The disease is perhaps disseminated by wind and insects. Recovery of diseased palms after the central shoot or even the greater part of the crown has withered sometimes occurs due to the growing point having escaped injury. The disease has closer association with relative humidity conditions than with rainfall. Mortality is heavier in cold weather when there is usually little rain (Butler, 1910).

Palms affected

Three species of palms are commonly affected in India, the palmyra (*Borassus flabellifer*), the coconut (*Cocos nucifera*), and the areca (*Areca catechu*). The greatest mortality occurs in palmyra, coconut palms being more resistant and arecanut even less liable to infection than coconuts. The disease can spread from one species of palm to the other.

Control

Once a palm is infected and unless the infection is noticed in the early stages, no curative measure could possibly save the palm.

Large scale field trials for the control of *Phytophthora* bud-rot were conducted by Butler (1910) and McRae (1923) in India. These trials involved the cutting down of affected palms at the soft region of the trunk just below the crown, destroying the crown by burning, coupled with the application of Bordeaux mixture to the young leaves of all palms within 25 yards of those affected. They laid special emphasis on the cutting down of obviously suspected crowns and burning them on the spot, as cases of dormant infections extending over a period of two years were common.

Much work on remedial measures for bud-rot has been done in Jamaica, where the flaming method seems to have originated. This consists in the scorching by the application of a flame gun the tops of all trees suspected to have the disease. Application of Bordeaux mixture to those in initial stage of infection with the hope of curing and to the neighbouring unaffected palms as a prophylactic measure has proved beneficial.

The following practices are found to check the disease :—

(1) Cutting and burning of badly infected trees on the spot.

(2) If the disease is detected in the early stages, when the heart leaf is just withering, application of Bordeaux paste on the crown after thorough cleaning and removal of infected material and if necessary, a few healthy leaves also is recommended. The wounded and the treated portion should be given a protective covering till the next emerging shoot comes out normal (Fig. *86*).

(3) A prophylactic spray of Bordeaux mixture to the apparently healthy palms adjacent to the diseased ones.

" False bud-rot " or Lightning injury

A case of sporadic bud-rot, termed " False bud-rot " observed in Malaya (Sharples, 1925) was for sometime confused with true bud-rot or the *Phytophthora* bud-rot. Similar injury due to lightning strike was reported by Dwyer (1937) from New Guinea. This form of bud-rot is characterised by the central shoot and the bud being affected only after the outer leaves have died. Sharples states " the disease in Malaya usually confused with bud-rot shows well marked symptoms in the stem and root. The sequence leading to the final appearance which results in the rotting of the bud appears to be a gradual loss of vitality; the crown grows sparse and thin and allows an easy entry of bud-rotting organisms which completely disorganise the bud tissue. The central leaves are attacked last, with all the other leaves collapsed and a single central leaf remaining stiff and upright and the ' bud-tissue ' still sweet and healthy ".

The roots die off without showing particularly noticeable symptoms. In palms up to 10 years old, the stem tissues remain soft but coloured deep salmon pink, with patches of mustard yellow tissue prominently intermingled. The discolouration extends up the stem in the typical ' Cone ' characteristic of a slowly progressing organism. In older palms, about 20 years old or more, the external symptoms are similar to those described above; however the wood is hard, discoloured dull red with the vascular bundles showing an abnormal lignification.

The affected palms are usually present in a circular area around the focus of the lightning strike. Seriously affected palms usually die first, while the surrounding palms succumb slowly due to the delayed effect and other secondary factors. The injured palms have a dried-up appearance; the dried up fronds often have the petioles split transversely which hang down loosely. Bleeding of the stem may also be noticed, with and without the association of borers and *Thielaviopsis* sp.

Marasmius palmivorus, *Fomes* sp., and *Polyporus* sp., are found on the dead wood. These fungi are the secondary effect of stem and root rot leading to the rotting of the bud. False bud-rot occurs in coconut, areca, palmyra and African oil palms.

DISEASES AFFECTING THE LEAF

This group comprises the diseases affecting the different parts of the leaf pinnae namely the ' leaf rot ', ' leaf blight ', ' bitten leaf ', ' petiole rot ', ' leaf break ', ' leaf droop ' and ' leaf fall '.

Leaf rot

Occurrence

' Leaf rot ' disease occurs in India in Travancore-Cochin (Kerala) and has a history of over 70 years. The ' Bitten leaf disease ' of the West Indies (Ashby, 1917) and the ' Frond Choke ' of New Guinea (Dwyer, 1937) have symptoms similar to those of the ' leaf rot '.

Nearly one-third of the coconut growing area of Travancore-Cochin is affected by the disease. The loss due to it on the basis of reduced yield of nuts alone has been calculated to exceed 5·6 million rupees per year (Menon and Nair, 1947).

Aetiology

The disease has been under investigation from 1916 onwards. Preliminary investigations were conducted by McRae in 1916 and later on by Sundararaman (1925). Sundararaman isolated a salmon coloured *Penicillium* like fungus (later recognised as *Gliocladium* sp.) from the affected leaves. Menon and Nair who have made extensive studies on this disease, report that three fungi are of frequent occurrence in the rotting material, namely *Helminthosporium halodes*, *Gloeosporium* sp. and *Gliocladium roseum*. *H. halodes* was more virulent than the other two which were active in conjunction with *Helminthosporium*. High humidity owing to dew or rain favours infection. Fungal spores enveloped in the droplets of dew or rain water adhere to the cuticle and germinate. Successful infection is established on tender leaflets in about 24 hours, by which time early symptoms of the disease appear on the leaf as tiny brown spots which rapidly coalesce and affect all the tender portions of the leaf. *Gloeosporium* sp. infects coconut leaves under conditions highly favourable to it or under the influence of predisposing factors like insect injury to the host or high humidity. *Gliocladium roseum* recorded by Menon and Nair is similar to the fungus reported by Sundararaman earlier. Infection trials indicated that it is a very weak parasite. In India, Mitra (1929) has recorded *Helminthosporium halodes* as a root parasite of wheat. Copeland (1931) describes *Helminthosporium incurvatum* as a secondary pathogen causing leaf spotting of coconuts in the Philippines.

Symptoms

The first visible symptom of the disease is a blackening and shrivelling up of the distal ends of leaflets in some of the inner whorls of leaves. On drying up, these are broken off in bits by the wind and the infected leaves assume a fan-like appearance which is characteristic of the disease. The central spindle also gets infected. Reddish brown spots and patches appear on the tender leaves and these penetrate to some distance into the interior of the shoots. The spots enlarge in size and a soft rot of the central shoot is gradually developed which in its later stages attracts a large number of insects and maggots. The central shoot grows and when the weather gets hot and dry, the rotten portions dry up and turn black and fall off in the wind. If the disease is allowed to proceed along unchecked, each successive central shoot of a diseased tree gets infected in turn and a stage is soon reached when all the leaves of the tree show disease symptoms. In severe cases, the rotten portions, on drying up, will be so completely cemented together that the central shoot is prevented from opening out. The severity of attack is generally apparent on the tender leaves. The ' leaf rot ' disease does not kill the palm outright, but it progresses slowly and steadily until finally the tree succumbs to the disease. Due to disease attack, the leaf lamina gets destroyed and this reduction in leaf surface adversely affects carbon assimilation, thereby causing considerable reduction in the yield of coconuts. ' Leaf rot ' disease has been observed on trees of all ages, but it generally flourishes on palms below 25 years of age (Fig. 79). It does not attack seedlings in the nursery stage. It is most severe during the height of the monsoon when the atmospheric humidity is high.

Control

Spraying the crown and leaves with Bordeaux mixture or copper fungicides, better cultivation of the gardens and the liberal use of potassic manures are advocated to combat the disease.

Bitten leaf disease

This disease is reported from Jamaica (Nowell, 1923). It has got great similarity with the 'leaf rot' disease of Travancore-Cochin. The causal organism however is different.

Symptoms

The disease derives its name from the appearance and shape of the affected leaves. The younger green unfolded and unfolding leaves appear bitten off at the ends or show successive leaflets lower on the stalks as broken or reduced to stumps. Those nearest to the heart leaf show spots on successive green leaflets which bend over and break and hang down at these points. Leaves just pushing up have black tips. Infection usually starts as a yellow discolouration with a brown edge along a narrow line beside the ribs of the leaflets and runs across all leaflets overlapping at that point. If the infection is high up, only the tips of leaflets become black. As the leaves get mature, the leaf stumps become dark and gummy.

Aetiology

Ashby (1917) recognised four types of 'Bitten leaf' diseases, viz., (1) Pine Apple Bitten Leaf disease, (*Thielaviopsis paradoxa*) ; (2) Hard or Little Leaf Bitten disease, (A species of yeast) ; (3) Phytophthora 'Bitten Leaf disease' (*Phytophthora* sp.) ; and (4) Rhinoceros beetle 'Bitten Leaf disease'.

Briton Jones (1940) however considered that these 'Bitten leaf' diseases mentioned by Ashby are not specific diseases, so as to command individual attention, but they are symptoms produced due to primary infection by *Phytophthora* sp. and secondary infection by *T. paradoxa* (*Ceratostomella paradoxa*). The yeast is considered to be a saprophyte following infection by the two fungi named above. According to Briton Jones, the intensity of disease incidence depends upon the extent of damage previously sustained by the incipient infection by *Phytophthora* sp.

Control

Cutting down and burning the infected leaves and the application of Bordeaux mixture to the foliage have been advocated as control measures.

Petiole rot

This is a disease of somewhat rare occurrence reported from Jamaica, making its appearance when the rainfall is high (Ashby, 1921).

Symptoms

The leaflets turn yellow and start dying from the tips downwards. The affected leaves soon dry up. Older leaves are affected first. Large, dark brown, sunken lesions are found on the midrib on both the surfaces, softening the tissues and resulting either in its breaking at the point of infection or hanging down by the side of the stem. Exudation of gum is a visible symptom of the disease.

Aetiology

The softening of the mid-rib tissues is stated to be caused by *Phytophthora* sp.

Control

Experimental control trials conducted in Jamaica did not yield conclusive results. Cutting out the diseased leaves and the application of Bordeaux mixture were not effective. Better results are reported to have been obtained by Ashby by wrapping the affected limbs in dried banana and coconut leaves and setting fire to them.

Leaf-break disease

This disease is of common occurrence in palms lacking vitality and is characterised by the breaking of the leaves at about half its length. Stockdale (1907) and Gadd (1920) reported it from Ceylon, Richards (1917) from Malaya and Nowell (1923) from the West Indies. Dwyer (1937) states that it is generally prevalent in closely planted groves in New Guinea.

Symptoms

The apical leaves break at about the middle and the broken terminals hang vertically downwards. Brown discolouration develops in the terminal leaflets and extends on to the mid-rib which later turns black. This discolouration spreads rapidly along the midrib causing the decay and death of pairs of leaflets in quick succession.

Aetiology

The fungus recorded as the causal organism is *Botryodiplodia* sp.

It is believed that *Botryodiplodia* usually attacks palms of low vitality and those which have been subjected to other diseases. The entry of the organism is through wounds and dead tissues.

Control

Control measures recommended are the cutting and burning of infected leaves, the application of Bordeaux spray to the foliage, improved drainage, manuring and better cultivation.

Leaf blight

Under this heading are included three diseases:

(1) The grey leaf spot or blight,
(2) The bacterial leaf blight, and
(3) The thread blight.

Grey leaf spot or blight

This disease is of common occurrence in all the coconut growing areas in the world. It was first reported from British Guiana (Copeland, 1931) and later on from Malaya, Mindanao, the Salier Island, the New Hebrides, the Bismark Archipelago, Ceylon, India, Trinidad, etc. Stockdale (1907, cited by Copeland, 1931) states that " when a large number of the leaves have been badly attacked by the disease, the terminal bud is left standing alone and it is only a question of time before this too falls over and the death of the palm results ". Horne (1908) states that the disease, though never known to be fatal by itself, probably does more damage to the coconut palm than any other fungal disease, by reducing the general vitality of the palms. In Jamaica, Ashby (1920) recorded a leaf disease with symptoms similar to this under the name ' Die back '.

Symptoms

The disease symptoms develop only on the outer whorl of leaves, *i.e.,* the mature or older leaves. They appear first as minute yellow spots encircled by a greyish band on the leaflets. These may measure from small specks up to 5 cm or more. Gradually the centre of these spots turns greyish white and the brown band darkens. Several of the spots coalesce into irregular, grey, necrotic patches. On the upper leaf surface, the globose, spherical, rectangular or ovoid black pycnidia of the fungus are formed (Fig. *87*). In advanced stages, the tips and the margins and at times the whole leaflets dry and shrivel giving the leaf a burnt appearance. Such a condition is referred to as ' blight '.

Aetiology

The causal organism of the Grey leaf spot or blight is *Pestalotia palmarum.* The organism penetrates the host when its tissues are tender and slowly establishes as a parasite.

Ashby regarded the disease as primarily due to root deterioration even though he isolated, *Diplodia* sp. and *Pestalotia palmarum* from the affected leaves. He considered these organisms as weakly pathogenic and suggested that the term ' early scavenger ' would be the proper description for them. Briton Jones agrees with this view and considers the disease as physiological in origin. He suggests bad drainage or potash deficiency to be factors that predispose the leaves to infection by the fungus. Improving drainage conditions, the application of potassic fertilisers and spraying the foliage with Bordeaux mixture are recommended as control measures.

Thread blight

This disease is reported by Bryce (1924 *a*) from New Guinea, as causing damage to the leaves of the coconut palms in New Ireland, and New Hanover. Dwyer (1937) reported its further spread gradually to other places. An analogous disease occurs in New Briton and Fiji (Simmonds, 1922) under the name ' Silver Film Disease ' and a similar disease is prevalent in Trinidad (Stell, 1930).

Symptoms

The disease affects the lower-most leaves since according to Briton Jones (1940), the humid conditions under the horizontal leaflets are congenial for the growth and spread of the organism. The fungus remains superficial on the leaflets. It grows and spreads along the under surface of the midrib in the form of slightly raised cord-like strands. As growth proceeds, these strands divide and sub-divide at regular intervals of about 3 cm into a fan of penicillate branches, the main cord keeping the lead throughout the entire length of the midrib and extending its hyphal tentacles to the leaflets. Ultimately the fungus ramifies the entire under surface and forms a thick weft of hyphae. On maturity, the mycelium turns brown. White patches appear on the upper surface of the leaflets in sharp contrast with the normal green shade of the neighbouring region, indicating that the epidermis has lost its coherence with the dead parenchymatous cells lying immediately below. These leaves are shed prematurely. In very serious cases, defoliation of about one-third of the crown takes place, attended by an immediate reduction in yield.

Aetiology

Very few investigators seem to have worked on this disease as its occurrence in other coconut growing countries is rare or infrequent. The causative organism was identified as *Corticium penicillatum* Petch.

Control

The control measures advocated by Bryce are cutting and burning of the affected leaves, spraying with Bordeaux mixture, and growing the palms under sanitary conditions. Briton Jones advocates larger spacing in planting as a measure of control for thread blight.

Bacterial leaf blight

Bacterial leaf blight has been reported from New Britain and New Guinea (Dwyer, 1937), as a serious disease of coconuts, during wet seasons. There is no evidence available of its occurrence in other countries.

Symptoms

The significant symptom of the disease is the drying up of the leaves from the tip downwards, the progress of infection being from the older leaves to the younger. The worst affected palms present the appearance of severe drought-affected trees. The infected leaflets may appear either at the base of the petiole or along the whole length of the rachis. Diseased as well as healthy leaflets in many instances appear intermingled on the rachis. Dark coloured lesions are found on the back of the midribs of the affected leaflets. These are usually large and irregularly margined, their edges being raised. They appear yellowish in colour, turning in course of time to a lighter green water-soaked zone, which, while fresh, is quite transparent when held up against light. On examination, almost transparent whitish bacteria are seen lining the edge. In the most advanced stages, the diseased areas become mottled in appearance and gradually become more pitted and stand out prominently, especially near the edges of the diseased zone.

Often confusion arises between the bacterial blight and leaf spot (blight caused by *Pestalotia palmarum*). However, the lesions caused by *P. palmarum* are smaller and are more or less with a regular margin. The dark pustules of *Pestalotia* infection are absent in the bacterial disease.

Aetiology

Dwyer attributes the disease to a species of bacterium which he has not identified.

Control

Adoption of the method of ‘ cutting off and burning ’ the affected materials is considered to be effective. As to this measure, Dwyer says that ‘ cutting off and burning ’ diseased leaves or any fallen trash may assist to control the disease but it is doubtful whether such operations would be effective and economic.

Leaf fall or Leaf droop

As the name implies, the disease manifests itself by the abnormal drooping of the lower leaves which gradually dry up and fall. In extreme cases, about one-third of the total number of leaves hang down disturbing the fruit bunches borne in their axils and result in premature nut-fall and button shedding. The bases of the drooping leaves are swollen and present soft discoloured patches. Species of *Phytophthora* have been detected in the discoloured portion (Dwyer, 1937).

Immature nutfall

Dropping of the buttons or the pistillate flowers before and after fertilisation is a common feature in coconuts. However, an abnormal shedding of a large number of buttons may be due to fungal infections or physiological or environmental factors (Gadd, 1923).

Nutfall or ' Mahali ' has been reported by Sundararaman and Ramakrishnan (1924) from Malabar, after the heavy south-west monsoon. Immature nuts are shed with their stalk-ends discoloured. The discolouration may extend up to the point of attachment of the nut to the inflorescence axis. Kernel of the affected fruit is rotten. These authors recorded the presence of *Phytophthora* sp. on the discoloured patches and their inoculation trials proved that the fungus is identical with *P. omnivora* var *arecae* (=*P. palmivora*) which causes the ' Mahali ' or ' Koleroga ' disease of arecanuts.

Petch (1917) and Dwyer are of the view that " leaf droop " and " nutfall " are different manifestations of the *Phytophthora* infection. However, Gadd states that " nutfall " may be caused by other factors either mechanical, i.e., due to the inherent weakness of the stalk of the nut or physiological, namely deficiency of water, nutrients, etc.

Nutfall is an associated symptom of several diseases like leaf rot, root rot and bud-rot. Johnston (1911) reported that in the incipient stages of bud-rot, " the falling of immature nuts, staining of the flower spikes, and the dying and falling over of the middle undeveloped leaves is a common feature ".

The view that the shedding of buttons is due to the attack of pests was first advanced from British Solomon Islands (Dwyer, 1937). The moth (*Acritocera negligens*), the beetle (*Diocalandra taitensis*), the coreid bug (*Amblypelta cocophaga*) and rats were associated with this trouble.

Premature fall of nuts is considered to be caused by physiological factors depending on soil and weather conditions, i.e., inadequate soil moisture, excessive moisture, water-logging or the deficiency of any of the major nutrients. Stockdale (1921) has described serious nutfall in Ceylon when there is excessive rainfall and in heavy soils in the Kurunegala district. Gadd reported that in Ceylon, water deficit following prolonged drought caused considerable fall of the female flowers or buttons. A very important factor is the available quantity of water.

Gadd cites the observations made in Indo-China where shedding of buttons, considered to be caused by deficiency of nutrients was remedied by the application of nitrogenous manures. However, the same author reported that similar treatment was not effective in Ceylon.

Fruit rot

This disease is observed frequently in every country where coconut is grown. Since the affected part is the fruit, its incidence causes considerable loss in yield. There are no reported cases of the palms being killed due to fruit-rot.

Symptoms

Rotting of the immature nuts is the chief symptom of the disease. The affected nuts fall down. Near the stalks, a discoloured area is developed, which will appear at first water-soaked and darker green than the rest of the surface of the nut. Later on, the lesions turn brownish in colour and appear as depressions due to the decay of the underlying tissues. The pathogen appears as a whitish matty growth on the surface. The rot extends into the husk and often even into the endosperm cavity if the shell has not hardened.

Aetiology

The causal organism has been identified as *Phytophthora omnivora*. The infection takes place on very tender tissues in the presence of moisture and in humid atmosphere ; the pathogen penetrates the fruit through the mesocarp and ramifies in that region. Consequently, decay sets in those tissues of the host leading to the shedding of the nuts.

The pathogen is active during the rainy season and survives in the fruit stalk during the dry weather, making itself manifest with the onset of favourable conditions.

Control

Fruit rot can be successfully controlled by spraying with Bordeaux mixture. To be effective, the treatment should be given during the pre-monsoon and post-monsoon periods. The former is meant to render the spore of the organism inactive and the latter to afford protection against fresh infection. In addition to spraying, the crowns of the palms, whether affected or not, should be given a thorough cleaning. The shed nuts should be collected and burnt.

Control measures for the crown diseases

In general the measures to be adopted for the control of the diseases affecting the crown may be summarised as follows:

(1) Eradication of the diseased materials and their destruction on the spot.

(2) Application of a copper fungicide, such as Bordeaux mixture, as spray or paste, on the infected and wounded surface, preferably during the pre-monsoon and post-monsoon periods.

(3) Prophylactic spray application of the fungicide on the apparently healthy neighbouring palms.

(4) Regular cultural and manurial practices to maintain the palms in normal vigour.

DISEASES AFFECTING THE STEM

Stem bleeding

Occurrence

Stem bleeding disease was first reported from Ceylon by Petch in 1906. Later on, it was observed to occur in India (Sundararaman, 1922), the Philippines (Lee, 1922), Malaya (Sharples, 1923), Andamans (Mitra, 1929) and in Trinidad (Briton Jones, 1940).

Symptoms

The characteristic symptom of the disease is the exudation of a dark reddish brown fluid from cracks in the outer tissue usually found at the lower portion of the trunk, about 2m to 3m, from the ground. The fluid turns black in colour as it dries up on the bark. The tissues beneath the bleeding patches become decayed and yellowish. In the early stages, the decay of the internal tissues is localised but as the disease progresses, these patches coalesce resulting in a general decay. The infection may occur anywhere on the trunk, but is rarely observed on the soft portion immediately below the crown (Fig. *80*).

The symptoms exhibited by young trees are different from those described above. On young palms, the spread of the disease is more rapid. The external patches do not indicate the extent of the internal decay. A general rot of the soft inner tissue takes place, leading to the formation of a cavity in the central portion of the stem and an accumulation of a thin yellowish fluid. The fluid gushes out when the cavity is opened. The decay when directed downwards to the bole, leads to the tree becoming hollow without any external symptoms. Fortunately such instances are not common. The disease generally destroys only the bark but has often also proved fatal. Trees with the patches, three feet long and six inches broad, exposing the vascular tissue, yet remaining normal in other ways, are not uncommon. Hence Briton Jones has concluded that " Stem bleeding " disease is not a major malady.

Aetiology

Spores of the fungus *Thielaviopsis* were observed in the liquid which oozes out. The same fungus was isolated from the discoloured tissue underlying the bleeding patches. The fungus was identified as *T. ethaceticus* (Went) by Petch which is identical to *Thielaviopsis paradoxa* (de Seynes) Von Hohnel or *Ceratostomella paradoxa* (de Seynes) Dade, the perfect stage of the fungus.

According to Briton Jones, this fungus however, cannot be considered as the primary cause of the disease but is only an *incitant*; in other words, the organism is only part of the causal complex. Petch (1908) has proved by inoculation trials that the fungus being a wound parasite, makes its entry through growth cracks which normally occur on the coconut stem. He further states that environmental factors are altogether outside the question as the disease occurs in all types of soils, manured or unmanured, inland or coastal, elevated or low-lying.

Different types of stem bleeding

As mentioned earlier, the bleeding observed on the coconut stem may be due to several reasons and it might also be of different types.

(*a*) Three distinct types of bleeding have been recorded in Malaya (Thompson, 1924) :

(*i*) the common type of bleeding due to the decay of the soft tissues about five centimetres thick, in which case, the bleeding takes place from all available cracks on the bark,

(*ii*) bleeding through abandoned white-ant galleries, and

(*iii*) bleeding from one single wound associated with a ' New disease ' recorded in Malaya.

(*b*) The ' Anabe roga ' disease of Mysore caused by *Ganoderma lucidum* is associated with bleeding of the stem (Narasimhan, 1930). Bleeding patches occur at the base of the trunk all round resulting in the slow death of the outer tissue ; it extends higher up on the trunk as the infection advances.

(*c*) Salgado (1942) reported the occurrence of the stem bleeding primarily due to physiological causes in Ceylon. He recognises them as :

(*i*) occurring on neglected gardens following heavy manuring and subsequent drought. In this case bleeding patches are reddish brown and circular, extending to a diameter of about seven centimetres and commencing from 0·5 m to 1 m from the base. The patches spread spirally about half way up the stem, and,

(*ii*) bleeding due to heavy rains following drought ; in this group there are two types of bleeding :

  (a) in ill-drained soils following floods which does not cause much damage ; and

  (b) on lands with fluctuating water table ; the bleeding under these circumstances is extremely severe, the patches almost reaching the crown and often causing the ultimate death of the palms.

Palms affected

Stem bleeding associated with *T. paradoxa* is prevalent on palmyra, arecanut, sugarcane and pineapple.

Control

The disease can be checked by completely removing the infected material by cutting it out by means of a chisel and dressing the wound with tar or Bordeaux paste. Since *T. paradoxa* is not considered a virulent pathogen, but a wound parasite, palms growing under unfavourable conditions having a large number of growth cracks are more susceptible to the disease as the growth cracks form the foci of fungal infection. Hence general improvement of the cultural conditions is indicated where the disease is of common occurrence.

DISEASES AFFECTING THE ROOT

According to Park (1928), the coconut palm may not succumb readily to attacks of root infecting fungi, since its root system being adventitious, the palm has the faculty of replacing injured or diseased roots under favourable soil conditions. Hence, symptoms brought about by root infecting fungi are not spectacular but their manifestation is invariably slow. Reports from Malaya, the Philippines, Borneo and New Guinea indicate that the soil conditions have a primary role in causing root rot. In the opinion of Dwyer, death due to fungal infection occurs only in the presence of predisposing conditions leading to the loss in vitality of the palms. Unfortunately, in none of the root diseases reported as due to various fungi, the primary role of the fungus has been proved by experimental data. Hence it will be advisable to consider these fungi as part of the causal complex and not as causal organisms.

Ganoderma lucidum

Occurrence

This fungus was first reported on palms by Butler (1906) in India. It was recorded in Ceylon (Petch, 1910 ; Small, 1927), New Guinea (Bryce, 1924*b*) and again in India (Narasimhan, 1930) causing the ' Anabe roga ' disease in Mysore. Sharples (1929) recorded the same fungus causing the stem decay of oil palm. In Trinidad *G. lucidum* occurs as a saprophyte (Briton Jones, 1940).

Symptoms

The symptoms associated with infection of this fungus vary according to the progress of the disease and the prevailing soil conditions. The earlier symptoms are observed in the older leaves which start drooping and withering and remain suspended around the trunk for several months before they are shed. Younger leaves remain green for sometime. The tree becomes barren due to the suppression of the inflorescence. The crown is reduced in size and the new leaves produced are successively smaller and yellowish in colour which finally wither as the bud decays.

In Mysore, in addition to these symptoms, bleeding patches occur at the base of the trunk all round. A brownish gummy juice exudes from these patches which slowly results in the death of the outer tissues of the trunk. As the infection advances higher up the trunk, fresh bleeding patches develop above the old ones. The tree succumbs to the disease in about two years. The sporophores of the fungus are not commonly met with but may sometimes be seen under the scaling bark close to the ground on an apparently healthy palm.

Control

The disease can be kept under control by the destruction of all the infected materials and the prevention of the spread of the fungus by digging isolation trenches about one-third metre wide and about a metre deep around diseased palms. Application of sulphur and lime to the soil around the trees was found to be beneficial (Venkatarayan, 1936).

Fomes sp.

Occurrence

Bryce (1924 *b*) in New Guinea observed palms affected by *Fomes lignosus* and *F. lamaoensis* (*F. noxius*) Corner. Petch (1910) and Small (1927) recorded a ' root disease ' of coconut from Ceylon. Petch isolated *F. lucidus* from the butt portion of affected palms and Small found *F. lignosus, F. lucidum* (*Ganoderma lucidum*) and *F. applanatum* in combination with other root-infecting fungi associated with the disease.

Symptoms

Bryce reports that the symptoms expressed by palms affected by *Fomes* sp. are similar to those recorded for *Ganoderma lucidum. F. lignosus* infections occur mainly on palms planted on lands newly cleared and where old stumps have been allowed to remain. The disease popularly called ' brown root disease ' is associated with the infections of *F. noxius* in the bole of the palm. The bole when cut open shows a honeycombed appearance, pale yellowish brown in colour and is light and tindery.

Control

Control measures recommended for these fungal infections are similar to those advocated for *G. lucidum*, namely the adoption of sanitary measures to eliminate infection. As Dwyer indicated, root rotting is not likely to be serious where the palm is vigorous and healthy and hence soil conditions favourable for the palm may be maintained.

Other root infections

Ashby (1921) recorded in the diseased roots of palms affected by ' die-back ', which is a deficiency symptom, the occurrence of *Rhizoctonia* and *Pythium*. Reduction in the nutrient demand of the tree by the removal of immature nuts and the regeneration of roots by the application of blue stone (copper sulphate) around the base of the trees, restore the trees to proper health.

In Florida, *Thielaviopsis paradoxa* was recorded by Giddings and Wood (1925) as causing root rot of seedlings. Thompson (1924) reported from Malaya ' a new disease ' considered to be a root disease evidently transmitted by root contact, since its spread was checked by digging isolation trenches.

WILTS

' Wilt ' in the broadest sense includes all plant diseases, the symptoms of which are expressed by the premature withering of the leaves and the flower bunches and the gradual loss in vitality of the plant, which is invariably its reaction to the failure in water supply. However, certain specific palm diseases are designated as wilt disease namely ' Tapering stem wilt ', ' Bronze leaf wilt ', etc.

Tapering stem wilt

Occurrence

Tapering stem wilt otherwise known as ' Pencil point disease ' was observed in several of the coconut growing areas. It was reported from Burma (Furtado, 1923), Ceylon (Bryce, 1921), Trinidad (Briton Jones, 1928) and Jamaica (Briton Jones, 1940).

Symptoms

The characteristic symptoms of the disease are the yellowing of the tips of the leaves, a reduction in their size, a gradual decrease in the girth of the trunk and a dwindling in size of the crown (Fig. *82*). The diminution in the size of the leaves and the diameter of the stem progresses until the small crown fails entirely to produce new leaves and the palm dies. The trunks are hard and the vascular bundles are reddish in colour.

Cooke (1950) reports from Ceylon two types of ' Tapering stem wilt '. One is the gradual tapering described above and another which is more rapid and designated ' quick tapering '. In the latter case the yellowing of older leaves and the paling of the younger leaves which are the earliest symptoms are accompanied by the unsymmetrical nature of the crown and the development of a black band just below the crown. Other symptoms observed are similar to those described earlier. Further examination of the tapering portion revealed that it was soft, black, corrugated and about a metre long. The growing point was small and rich in potash. There was extensive root decay.

Bronze leaf wilt

Occurrence

Briton Jones (1928) reported from Trinidad a wilt disease of coconut designated as ' Bronze leaf wilt '. In the West Indies it occurs in Jamaica, British Guiana, St. Lucia, Tobago and Trinidad. A similar type of wilt was recorded in Ceylon by Park (1932). The disease is prevalent in both clayey and sandy soils and in soils which induce shallow root system (Park, 1932; Bain, 1937; Duthie, 1938).

Symptoms

The typical symptom of the disease, as the name signifies, is the bronzing of the leaves and their wilting and subsequent shedding. In a healthy palm, the lowest and the oldest leaf including the stalk, on aging, turns to yellow and later bronze or reddish brown colour and is defoliated. Usually in a normal palm, one or at times two of the oldest leaves show such yellowing and discolouration prior to shedding. On the other hand, in a palm affected by bronze leaf wilt, more than two leaves show yellow and bronze colouring coupled with the yellowing at the tips of the next two or three leaves. Wilting progresses in absolute regularity in the order of age from the oldest to the youngest (Fig. *83*). The discolouration sets in at the tip of the leaf and extends backwards to the base. Before the youngest leaf is affected, the cabbage is killed by bacterial rot which starts at the base of the leaves and spreads inwards to the cabbage. Bronzing of the leaves is accompanied or preceded by the shedding of the nuts; the spathe also turns brown from the tip backwards towards the base slightly in advance of the discolouration of the tips of the leaves, in the axils of which the spathes are borne (Briton Jones, 1940).

Internally, a reddening of the ground tissue towards the centre was found in rare instances by Park (1932) and Briton Jones (1940) observed a general reddening of the ground tissue. According to Park, roots were not affected.

Aetiology

Based on the experimental evidence recorded, environmental factors leading to a rapid water deficit is considered to be responsible for inducing the disease (Martyn, 1934; Bain, 1937; Briton Jones, 1940). The adverse soil conditions include water-logging, too open soils or soils which drain off quickly, or an impermeable strata below the surface soil which lead to a shallow root system and result in effects similar to drought. The ' wilt ' in Ceylon was preceded by drought in certain instances and it was most severe on poorly cultivated estates and on land, which, in wet weather, becomes water-logged and swampy. Briton Jones (1940) is of the view that the trouble might be due to " physiological drought ".

Control

Improvement in soil conditions which will maintain an equilibrium between root absorption and leaf transpiration during the dry season will tend to check the disease. Recovery due to watering although temporary, has been recorded by Briton Jones and Bain. Bain also recommends watering in conjunction with application of potash and ammonium sulphate.

WILT DISEASES OF UNKNOWN ORIGIN

In addition to the ' tapering stem wilt ' and the ' bronze leaf wilt ' described above, there are several other instances of ' wilt ' reported from many of the coconut growing areas. The general symptoms of these are the yellowing of the leaves, shedding of immature nuts and the loss in vitality of the palm leading to its final death. Minor variations in the sequence of the appearance of the symptoms, their intensity and the susceptible age of the palms have been reported. The causal factors of these wilts are not yet fully understood though fungi have been found associated in several cases. They are described below :

West Indies

Stockdale (1907) reported a disease of coconut from Trinidad designated as ' root disease ' caused by *Lasiodiplodia* (*Botryodiplodia theobromae*). According to Petch (1910), the symptoms observed are the wilting and yellowing of the leaves which begin at the tips and gradually spread all over the leaflets. The leaves remain suspended for a considerable time before they are shed. Subsequent to the yellowing of the leaves, the immature nuts are gradually shed and the flowers produced later do not set. Roots of the diseased palms are affected, the cortical tissues being destroyed and a fungus found ramifying them.

Jamaica

In 1907, a wilt disease was reported from Jamaica (Anon, 1908). The earliest symptoms to appear were the wilting and yellowing of the older leaves ; sometimes the middle ring of leaves also might show yellowing. At times the petioles break, leaving the stumps of the wilted leaves on the crown. Nuts are shed gradually and the female flowers produced subsequently do not set. Roots of the diseased palm are also affected from the early stage. Later, the stem of the diseased tree develops red discolouration, commencing from the internal tissues at the ground level and extending upwards and may be traced up to the wilted leaves. The cortical region of the roots is disorganised and the roots are found to harbour *Botryodiplodia*.

Ceylon

The disease reported from Ceylon by Petch (1910), Small (1927) and Park (1928) as ' root disease ' of seedlings and other palms, has symptoms similar to that of wilt. The external symptoms are those of degeneration, namely, withering and drooping of the outer leaves which remain hanging for a long time, diminution in the size of the new leaves produced, reduction in yield by the shedding of immature nuts and suppression of the flowering bunches. Sometimes, a tapering of the stem and the final death of the palms are observed. Several fungi have been found associated with the disease. *F. lucidus* (=*Ganoderma lucidum*) was found to occur in the butt portion of the diseased palms (Petch, 1910 and Park, 1928). Small reported the occurrence of *Diplodia* sp., *Poria* sp., *Fomes lucidus*, *F. lignosus*, *F. applanatum*, *Polyporus zonalis* and *Macrophomina phaseoli* Maubl. Ashby [= *Rhizoctonia bataticola* (Taub) Butler] in the roots of the diseased palms. Of these, *M. phaseoli* was considered by Small as a primary pathogen. However, the authenticity of this statement was questioned by Briton Jones (1928) in whose opinion *M. phaseoli* is a saprophyte capable of attacking coconut roots only when the latter are weakened due to other fungal infections or adverse environmental conditions. Park is of the view that *M. phaseoli* found in the dead and apparently healthy roots is mycorrhizal in character and that the symbiotic relationship may transform itself into a pathogenic one when, due to the influence of unfavourable conditions, the host is predisposed to fungal infection. Park further states that unfavourable soil conditions like drought and flooding may induce these disease symptoms. Other adverse soil conditions listed by him are :

(*i*) the presence of an inhibiting factor like a hard pan at a certain depth below the surface soil, toxic products, excessive acidity or alkalinity, etc., and

(*ii*) the absence or insufficiency of a soil constituent essential for normal growth such as lime, phosphate, nitrogen and potash. The disease takes about ten years to kill a tree.

New South Wales

Frogatt (1914) reported a wilt disease affecting the trees just coming into bearing; young trees are not generally attacked. The disease is rapid, often killing the tree within three or four months.

Mauritius

A wilt of coconut, the external symptoms of which appear to be similar to " Red ring disease " namely desiccation of the leaves from the base upwards and of the pinnae from the tip downwards was reported. Nematodes were not detected in the diseased palms. Occasionally *Botryodiplodia* was found in the roots of the affected palms (Shepherd, 1926).

India

Occurrence

A new disease of the coconut palm was reported from East Godavari (Andhra) ; the first occurrence of a severe infection was noticed in 1940 and a more wide spread incidence after the cyclone in 1949. The incidence of the disease is sporadic and its spread erratic. Inland clayey soils were found to favour the disease more than the coastal sandy soils. Trees of all ages except those below ten years are affected. The disease is more prevalent among the heavy bearing middle aged trees.

Symptoms

The main symptom of the disease is that normal bearing healthy palms suddenly bear heavily for about two years and then a marked reduction in growth and productivity sets in. Leaves become pale yellow in colour, their size is reduced, the leaflets of the opening central leaves do not unfold properly and present a fasciated appearance. Steady reduction takes place in the number of spadices produced and the size and number of nuts. The nuts are shrivelled and atrophied and in some cases show longitudinal cracks and gumming at those cracks. In such nuts the kernel is not formed. With the advance of the disease, the capacity of the infected trees to produce inflorescence is badly impaired and they become barren with sharply tapering stem and reduced crown. The leaves are shed in quick succession and the tree succumbs to the disease within the course of a few years.

The root system of the diseased tree showed distinct deterioration and decay. The extent of root decay and the capacity to put forth fresh roots appeared to be correlated with the severity of the disease. The rotting had not affected the stem and the bole of the diseased palms.

Aetiology

Preliminary investigations did not reveal the presence of any pathogenic organisms, nor did the soil analysis indicate deficiency of nutrients. Investigations on the aetiology are in progress.

Maturation wilt

This is a type of wilt affecting young palms from five to eight years old, and in most cases those that had just commenced to fruit. ' Maturation wilt ' which is of a temporary nature is distinct from the more permanent and serious wilt diseases of the mature palms.

Occurrence

' Maturation wilt ' has been reported from New Guinea (Dwyer 1937), being prevalent in the inland plantations, a great proportion of which is exposed to the strong north-west winds.

Symptoms

The symptoms of the disease as described by Dwyer are as follows :

" Pronounced tip withering occurred on the centre leaves of the affected palms, and some dying back was also seen on the outer leaves. On the back of the petioles (leaf stalks), pale brown streaks were seen. These sometimes showed up near the tip of the leaf or near the base, but, as a general rule, commenced about two-thirds of the way up from the base. The scattered lesions, although moist in appearance, were quite firm, but later they tended to spread and link up, becoming sunken below the general level of the outer surface of the mid rib. Eventually the diseased portions split longitudinally, exposing the fibres after the ground tissues had fallen away, and the unhealthy parts become quite dry and hard.

A cross-section made after drying out had occurred showed a pale, sulphury-yellow layer immediately underneath the sunken tissue; this merged into a brown discolouration extending through the petiole almost to the inner surface. In longitudinal section, the discoloured portion showed up as full reddish-brown streaks. Such rotted portions were seen in some cases to extent below the fibrous tissues at the base of the leaves, but in no case did it appear to kill the palms. A tip-wither of the leaflets which extended from the top of the fronds almost to the base generally occurred concurrently with the stem-rotting mentioned.

Around the edges of the withered sections on the leaflets a distinct halo was noticed in some cases and the ' die-back ' from the tips was very distinctive. Pale areas with brown margins also appeared in the centre of the leaflets. The above symptoms only showed up on the fronds comprising the crown, while the older leaves were usually not affected."

Generally the affected palms are tall, very erect often presenting a frond-chocked appearance. Only bearing palms and those at the flowering stage are affected. The nuts from the diseased palms show an unhealthy, yellow colour. Sporadic bud-rotting develops in severely affected palms.

Aetiology

The fungus *Pestalotia palmarum* and the insect *Brontispa froggatti* were scattered widely in the plantation and the disease was more intense where a heavy infestation of white-fly, *Aleurodicus destructor* and unidentified scales were present. However, no virulent pathogenic organism was associated with the diseased specimen.

Detailed investigations indicate that the disease is localised and physiological in origin. The adverse soil conditions prevalent in the areas where the disease occurs were considered the causal factors, although the disease was also observed in palms growing in soils well suited for coconuts. An important feature of the areas was the presence of large depressions. Underneath the area where the palms are affected, a water channel which carries away the rain water that readily penetrates to the lower layers was suspected. The root system of the diseased palms was found to be very shallow. The appearance of the disease was associated with a pronounced spell of dry weather following heavy rains. Insect attack and infections by weakly pathogenic fungi are considered to aggravate the disease, as with the incidence of abundant rainfall and the adoption of sanitary measures the palms recovered.

Sudden wilting of coconut palms under certain changed soil conditions has been noticed (Pandalai *et al.*, 1954), and is discussed in Chapt. XIII.

PROBABLE VIRUS DISEASES

Under this heading three major destructive diseases of coconuts in different parts of the world are described. They are: the ' Cadang-cadang ' disease in the Philippines, the ' Unknown disease ' in Jamaica and the ' Wilt (root) disease ' in India. All these diseases have certain features in common such as their apparently systemic and infectious nature; none of them could be ascribed to parasitic organisms or unfavourable soil conditions alone. These diseases are suspected to be of virus origin. In no case, however, the experimental evidence so far obtained in favour of this hypothesis has been conclusive enough to definitely establish the virus nature.

Cadang-cadang disease

History

' Cadang-cadang ', locally meaning growth failure or running out disease, is a highly destructive disease of coconuts confined to the Bicol province of the Philippines. The disease seems to have been prevalent there for over forty years. By 1953, the disease was estimated to have destroyed about 552,700 coconut palms, representing a financial loss of about 22,000,000 pesos (Calica and Bigornia, 1953). Only bearing trees exhibit clearly distinguishable symptoms, though young seedlings have also been observed to show mottling, water soaked areas, necrosis, etc. However, the young palms do not die but seem to grow well (De Leon, 1951).

Symptoms

The symptoms of the disease have been described in detail by Ocfemia (1937), Celino (1947), Reinking (1950) and De Leon (1951). The first observable symptom is a reduction in the size and number of nuts produced. It is estimated that nut production ceases in about 3 to 4 years. When nut production decreases, the outer leaves develop a bronze yellow colour especially at the tips of leaflets. The spots on younger leaves are about 1 mm in diameter, which enlarge to about 3 to 4 mm and have a tendency to coalesce, which makes the pinnae look yellowish or chlorotic in appearance. The pinnae appear slender, tend to bend over or break in the middle and probably due to their chlorotic nature, dry up earlier than those on the healthy palms. After yellowing has set in, no nuts are produced, although spathes are produced in abundance. Female flowers are fewer in number; these either shed or develop into undersized nuts. In the late stages, the dwarfed inflorescence that is put out bears only male flowers. The inflorescence dries up and persists on the tree. As the disease progresses, the leaves produced are very much shorter and smaller and are closely bunched at the top of the crown (Figs. *84* and *85*). Gradually the stem tapers, the crown is reduced to 8-10 short, stiff, upright, bronze yellow leaves which fall off leaving a pointed trunk. Many of the roots of the infected palms are discoloured, the cortex of which may be disorganised, and some of the roots die off and rot. From the appearance of the first symptom, the disease takes about 2½ to 7 years to kill a tree (Kent, 1953). Recovery is rare.

Aetiology

The disease appears to be infectious although Fajardo (cited by Kent, 1953) suspects a nutrient deficiency as the cause. So far, no parasitic organism which could be considered the cause has been found associated with tissues of diseased palms. Ocfemia (1937) suspected the disease to be of virus origin. Celino (1947 *a*) reported successful transmission of the disease by needle-prick inoculation. According to Kent (1953), Calica and Bigornia secured transmission using insect vectors, *Cicadella unimaculata* and *C. bipunctifrons*; nevertheless this evidence is not conclusive and can be treated only as indication of the disease being of probable virus origin.

Alternate hosts

De Leon and Bigornia (Kent, 1953) believe that the same or similar disease occurs naturally on other palms including *Areca catechu, Adonidia nerrillii, Corypha elata, Caryota cummingi* and *Livistona rotundifolia*.

Control

The following control measures are recommended to check the spread of this disease (De Leon, 1952).

(1) Diseased trees should be cut down and burnt as soon as they cease producing normal sized nuts.

(2) No plantation should be established in Bicol until suitable control methods against the disease are developed.

(3) A suitable insecticide may be sprayed against the suspected vectors.

" Unknown disease "

Occurrence

This is the most serious disease of coconuts in Jamaica and has also been noticed at several points in the North Caribbean Coast of Panama and Central America. It was first noticed in Jamaica in 1872. Ashby (1915) named it as " West End bud-rot ", since it occurs only on the western side of the island and to distinguish it from the typical bud-rot caused by *Phytophthora*. It is also called the ' Petersfield disease' owing to its constant occurrence in that area and almost the same disease is known to occur in Cuba, Cayman Islands, Haiti and Bahamas (Martyn, 1948). For sometime it was considered to be the same as the ' Bronze leaf wilt ' in Trinidad (Martyn, 1945). Later investigations by Leach (1946) and Martyn (1948) proved that in view of the aetiology and the environmental conditions under which the two diseases occur, the disease in Jamaica is different from that in Trinidad and was designated as the ' Unknown disease '. Recently the disease has been referred to as " Lethal yellowing " (Nutman and Roberts, 1955).

Palms of all ages are susceptible to the disease. It is prevalent on a variety of soils but is not very serious on lime stone soils (Martyn, 1948).

Symptoms

The first visible symptom in bearing palms is the shedding of young and maturing nuts, all of which may be shed within one to four months. When nut-fall commences, in the most recently opened inflorescence, the tips of the flowering branches and the terminal flowers may be discoloured (brown). This discolouration generally occurs before the spathes split open and the diseased spathes usually open prematurely. In course of time, the affected flowering branches wither off. The foliage shows signs of discolouration, that is, bronzing of the lower leaves, only after all the nuts have fallen. Once the bronzing has set in, all the leaves are affected in quick succession. The old leaves remain in their normal position until they fall suddenly without hanging around the stem. In due course, the heart leaf withers and the tissues of the heart, if examined at this stage, will be seen to be rotten. Roots of infected palms show signs of becoming rapidly moribund and tyloses appear in the vessels. In about three months from the appearance of the first symptom, the palm succumbs to the disease. Diseased trees rarely recover.

In non-bearing palms, the earliest symptom observed is the fall in the growth rate of the younger leaves. Later the outer leaves become bronzed and the youngest heart-leaf still unfolding, dries out in patches, which becomes brown and papery. This is accompanied by a heart-rot as in bearing palms.

The disease symptoms affecting the inflorescence, namely, the discolouration of the flower branches and the terminal flowers as well as the shedding of immature nuts, appear unilaterally on the palm, this unilateral effect being more marked when the rate of nut-fall is slow. (Leach, 1946 ; Martyn, 1948).

Aetiology

On studying the effect of climatic and soil conditions on the incidence of the disease, Leach (1946) states that seasonal conditions which promote active growth favour the disease, the more luxuriantly the palms grow and the better yielding capacity they have, the more susceptible they are to the disease. The symptoms presented in the nuts and inflorescence indicate a physiological break-down; however, it cannot be ascribed to drought as the disease occurs throughout the year.

Leach suspected that the disease could be caused by a micro-nutrient deficiency and some of his preliminary analyses suggested a deficiency of manganese. Spraying with manganese salts and injection of salts of iron, boron, magnesium and zinc had no beneficial effect on the condition of the diseased palms. Innes (1949) also showed that a deficiency of manganese is not the causal factor. Hansen (1952) suggested that the disease occurring on lime stone soils is probably due to the release of strontium by sea spray. The occurrence of the disease on very varied soil types, both acid and alkaline, in Martyn's (1949) opinion, does not favour a soil factor to be the primary cause of the disease ; nevertheless the fact remains that the disease tends to spread at a uniform rate throughout any area where the soil is uniform, whereas in fields consisting of different types of soils the rate of spread of the disease varies.

According to Martyn (1949), the spread of the disease along the north-west coast of Jamaica is indicative of its infectious nature. The spread is confined to short distances along the coastal areas both in Jamaica and Bahamas. No parasitic organism was found associated with the diseased tissues and the artificial inoculations conducted by him using the bacteria isolated from the rotting tissues of the cabbage failed to produce the disease. Similar attempts made by Leach (1946) with *Rhizoctonia* sp. isolated from the root of the infected palms gave negative results.

Since the disease appeared to be infectious but could not be ascribed to a parasitic organism, Martyn (1949) considered that it could possibly be caused by a virus. However, his trials to transmit the disease by needle-prick inoculation and by abrasives failed. He is of the view that the disease is not likely to spread by an air-borne vector considering the irregular nature of the spread of the disease and the improbability of a vector penetrating the growing point or the closed inflorescences where the primary symptoms occur. His attempts to control the spread of disease by DDT spray did not give encouraging results. He suggested that a soil inhabiting organism might carry the virus and spread the disease to uninfected palms. This theory is substantiated by the rapidly epidemic nature of the disease when it starts on certain soil types where coconuts are growing close together. The symptoms recorded, namely, the fall in growth of the young leaves and the unilateral appearance of floral discolouration and nut fall in bearing palms are suggestive of the absorption, presumably through the roots of some virus or a substance of toxic nature which initially causes the cessation of growth in the youngest and the most rapidly growing tissues, followed by their death and further internal changes leading to the yellowing of the older leaves. Yet attempts to

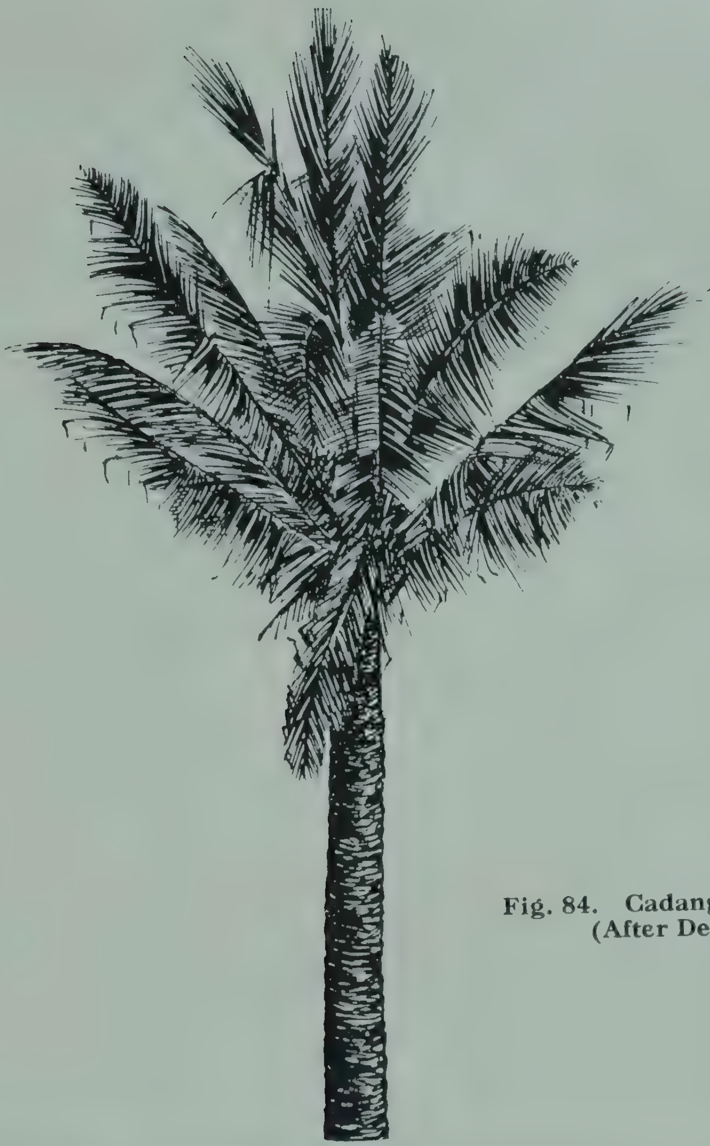


Fig. 84. Cadang-Cadang disease
(After De Leon, 1951)

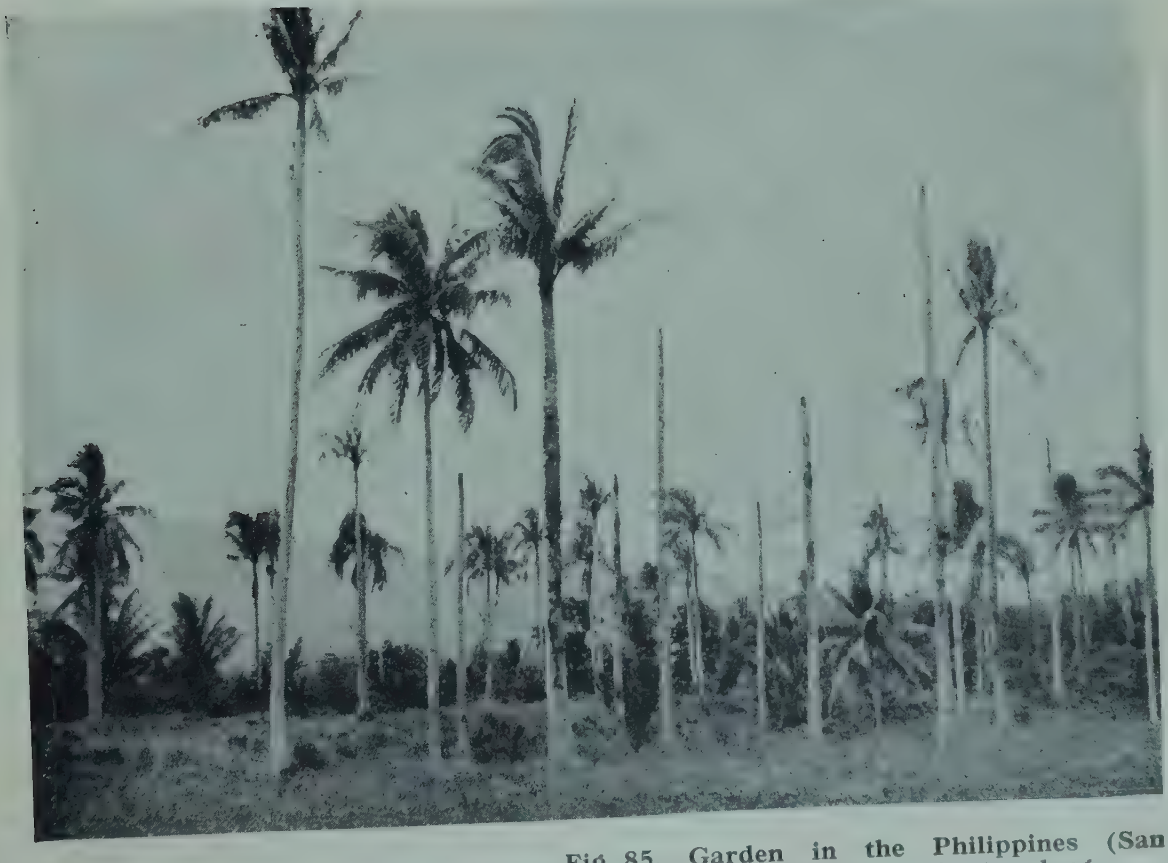


Fig. 85. Garden in the Philippines (San Miguel) damaged by cadang-cadang

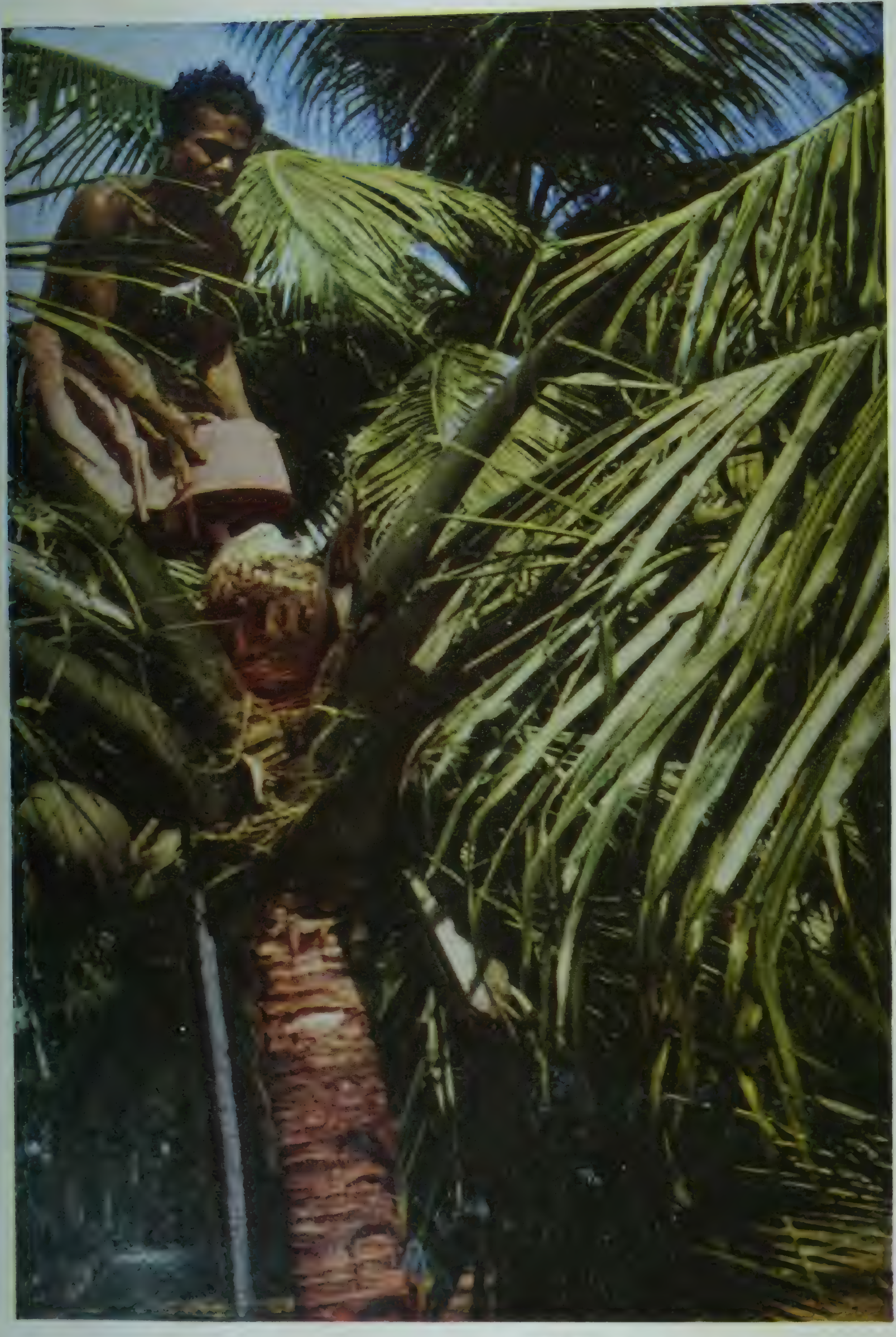


Fig. 86. Palm being treated against bud rot

transmit the disease by using soil and root debris from diseased areas proved unsuccessful. Latest investigations (Nutman and Roberts, 1955; and Martyn, 1955) comprising epidemiological data, symptoms, the occurrence of double nuclei in the cells of the affected palms, and positive serological reactions indicate that the disease may be due to a virus.

Control

Martyn (1948) has suggested that infected palms should be cut and burnt especially in gardens when the disease is starting to appear but not yet widespread. Use of resistant varieties (Malayan Dwarf) is, according to Nutman the only practicable method of control.

The wilt (root) disease of Travancore-Cochin

Occurrence

The wilt (root) disease is the most important disease of coconuts in the Travancore-Cochin area of Kerala affecting about a lakh of acres. It is estimated to cause an annual loss of about rupees 10 million. The disease has been prevalent in the State since about 80 years and is believed to have become significantly manifest after the great floods of 1882. The disease is at present apparently confined to Travancore-Cochin area and seems to be gradually extending northwards and southwards within the State.

Palms above 6 years of age appear to be most susceptible. Clear symptoms of disease have not so far been noticed on seedlings below 4 years old. The disease appears to be systemic and infectious, and is prevalent in all the types of coconut soils in the State. Recovery of diseased palms has not been observed (Menon and Nair, 1949).

Symptoms

The characteristic symptoms of the disease are—general wilting of the leaves, flaccidity and ribbing of leaflets and necrosis of leaf tips. In many cases, a general chlorosis is also prevalent on the older leaves. On close examination of the inner leaves, in most of the diseased palms, the leaflets show a large number of chlorotic streaks which later become brownish and necrotic. As the disease advances, the whole crown gets smaller due to a reduction in the number and size of the leaves (Fig. *88*). Shedding of immature nuts, if the tree is bearing at the time of infection, is an initial symptom in some cases. The vitality of the reproductive system is adversely affected with the result that the diseased tree produces small spathes with fewer female flowers and consequently smaller number of nuts. The quality of the nuts in every respect deteriorates. In an advanced stage, the crown gets very much reduced in size, ceases to produce flower-bunches and finally succumbs to the disease. The root system of the affected palm manifests considerable deterioration. Most of the rootlets and the main roots start drying from their tips backwards. Cracks, blotches, etc., are visible on older regions, the cortex turns brownish in colour and dries up in flakes. In certain instances where the roots remain apparently healthy, even in advanced stages of disease their absorbing region gets covered with a hard hypodermis and results in a cessation of normal functions. Production of new roots decreases with the progress of the disease.

Aetiology

Butler (1908) isolated a species of *Botryodiplodia* from rotten roots of infected palms and thought that the root rot caused by the fungus was probably sufficient to produce the disease. Varghese (1934) gave a detailed account of the disease and discussed its probable causes based on the evidence collected during several years. The extensive investigations carried on by Menon and Nair (1951) revealed the complex nature of this disease which in many respects is comparable to the ' Unknown disease ' in Jamaica and ' Cadang-cadang ' of the Philippines. They observed the constant occurrence of *Rhizoctonia bataticola*, *R. solani*, and *Botryodiplodia theobromae* in diseased roots. The possible disease-causing role of these fungi was examined by Radha and Menon (1954) and they suggested that the part played by the fungi may be secondary, considering the cosmopolitan occurrence and the facultative nature of the organisms concerned. Further studies have shown that root rotting may be entirely absent in some palms in early stages of wilt and it therefore appears to be a secondary symptom (Nagaraj and Menon, 1955).

Investigations so far conducted on the soil and nutritional aspects of the aetiology of the disease have failed to indicate that any macro or micro nutrient deficiency could be the direct cause of the disease, although the possibility still remains of this being an indirect cause. A comparative study of the soils from the healthy and diseased areas for their complete chemical and mechanical composition, base exchange property, organic matter status, C/N ratio and pH, has revealed that there are certain significant differences between the two. Total calcium, available potassium, base exchange capacity, percentage base saturation and pH of soils are found to be lower in most of the disease affected regions than in healthy tracts. These aspects are discussed elsewhere.

High water table or poor drainage is generally a common feature of the diseased localities. In general, prolonged water-logging of the soil deteriorates root health to a very considerable extent and thus decreases the disease resisting capacity of the palms. Such conditions act as predisposing factors for the onset of fungal attack and facilitate the pathogenic activity of weak facultative parasites. Water-logging of the soil was proved to be a predisposing factor for the infection of *R. solani*, *R. bataticola* and *B. theobromae* on palms (Menon *et al.*, 1952). Park (1928) has observed that the unfavourable soil condition may be responsible for the change over of *R. bataticola* from its mycorrhizal existence to that of a pathogen.

Apart from the physical conditions of the soil exerting an adverse effect on the general health of the palm, certain micro and macro-nutrients also might probably have a role in orientating this condition of the palm. Sankarasubramoney *et al.* (1954) have shown that there is a general tendency for most of the nutrients especially nitrogen, potassium and phosphate (calcium and magnesium also, unpublished data) to accumulate in the leaf tissues of the diseased coconut palms. Whether this accumulation of the important plant food ingredients in the leaves of diseased palms is the result of impaired physiological process or whether this condition is due to inadequate translocation are to be further investigated.

Results of mechanical inoculation experiments and insect transmission trials conducted in the open under field conditions, have indicated (Nagaraj and Menon, 1956), that the disease may probably be a sap-transmissible virus disease and that the banana lace wing bug *Stephanitis typicus* may be one of its probable vectors.

Control

As the disease is infectious, the infected trees, especially in gardens where the disease is not widespread should be cut and burnt. General improvement of the cultural and manurial practices might mitigate the disease to a certain extent.

DEFORMITY GROWTHS

This group embraces all the cases of growth that impart a stunted or twisted appearance to the palms. The most important of these are " Head droop " and " Frond choke ".

Head droop

The phenomenon termed " Head droop " is otherwise known as ' cork screw ', ' cabbage droop ' or ' strangle disease '. ' Head droop ' is of frequent occurrence in New Guinea and New Ireland and stray cases are reported from Bougainville and New Britain.

Symptoms

The top bends over and in extreme cases the whole stem makes a semi-circular growth while the leaves appear collected and twisted forming a distinct rosette with a few old leaves short and dying back. Often cases of the whole stem taking a distinct loop or ' S ' shaped curve are also met with. The ' droop ' period is variable and may extent up to 12 months or more before the head begins to take its normal course of development. During the period of droop, no spathes are developed. Rarely the palm dies before the head has turned to its vertical position (Frogatt, unpublished, cited from Dwyer, 1937).

Aetiology

The cause of the disease has not yet been definitely established. Various suggestions have been put forward as to the cause of ' head droop '. The idea that ' head droop ' may be a deficiency disease seems to be improbable considering the wide occurrence of this condition in rich soils and often on the heavy bearing palms. Another opinion is that it may be a virus disease (Dwyer, 1937). Yet another possible cause is the mechanical injury inflicted by insects in the early stages, which weakens one side of the trunk and eventually leads to the twisting of the crown. The association of insects with this growth condition has been recorded by Simmonds (1924) though he himself was sceptic over it. However, it is possible that the trees may be injured by big beetles. It was believed that the original damage caused by whirlwinds to the cabbage led to the loosening of the leaves forming the central structure of the palm. Anatomical examination of an affected palm by Dwyer has thrown some light on this disputed point. He explains the position like this: ' The fronds comprising the head of the palm were all bunched together and it appeared that the central leaves were the first to bend over and eventually the extra weight on one side caused the whole head to fall over '. In the absence of any evidence to substantiate the various hypotheses and an associated specific organism, it may be presumed that the phenomenon is an abnormal development due to physical injury and consequent growth strain.

Control

Releasing the strain by pruning the younger leaves, application of insecticides, loosening the congested leaf sheaths etc. are some of the control measures helpful in curing the trouble.

Frond choke

Dwyer (1937) reported a sporadic appearance of ' frond choke ' from New Guinea. The deformed growth in this instance, as the name implies affects only the leaves. The terminal fronds tend to stand upright and their growth is very poor. The older leaves at the periphery are crowded around the bud with their bases held together tight instead of remaining free. Fronds developing in succession become small. The palm presents a sickly yellow appearance and appears to lack vigour.

Aetiology

The aetiology of this disease is still under investigation. Dwyer suggested that it is aggravated by close planting, unfavourable soil conditions, etc. The possibility of its being a virus disease has also been mentioned by him. However, the theory of a physiological derangement is more favoured in view of its occurrence in isolated places.

The ' Little Leaf disease' described by Ashby (1917) seems similar to the ' frond choke ' as observed from the deformed, crinkled and dwarfed leaves. According to him, the rigidity imparted to the central shoot by these indurated leaf stalks could be the apparent cause of crumpling and distortion of the leaves (Dwyer, 1937). In his opinion ' frond choke ' and crinkled leaf may be of genetical origin as some of the palms remain permanently affected in spite of the remedial treatment.

Control

Spontaneous or natural recovery of affected palms is very rare. Recovery is facilitated by incising the hardened portion so as to clear the mechanical obstruction to the emergence of the subsequent shoot. The treated palms respond quickly to cultural and manurial operations.

RED RING DISEASE

' Red Ring disease ' described as an endemic disease in South and Central America has been reported from Brazil (Joffilly, 1948), Venezuela, Columbia, Panama and British Honduras (Martyn, 1953). This disease was first attributed to a fungus of the genus *Botryodiplodia*. Extensive mycological investigation of material from diseased tissues showed that the affection was not due to any fungal parasite. Nowell (1918) found that a nematode was constantly present in the affected tissues of coconut trees in Grenada and put forward the theory that it was due to the parasitism of this worm. This has been supported by later investigation conducted by him (1923). The characteristic symptoms of the disease have been reproduced by him by placing small pieces of infected tissue at the leaf axils or inserting such pieces of material through wounds at the bases of the leaves.

The first symptom is a progressive yellowing and browning of the leaves. The early stages of progress are rather indistinguishable in appearance from the natural dying off of leaves due to drought, water-logging or poor condition of growth. The difference becomes apparent by the process of discolouration which soon affects the healthy leaves and spreads to those in which the leaflets are not even fully expanded. At this stage, the tree is conspicuous by its rich colouring of brown, orange and yellow in all but the central tuft of leaves. These conditions may develop within the first three weeks of infection. The tree starts shedding immature nuts. Secondary infection by bacteria sets in among the softer tissue at the apex of the stem.

Internally, a cross section of the stem (Fig. *81*) shows a well marked zone 2·5 cm to 4 cm wide and beginning 2·5 cm to 5·0 cm from the periphery, in which the ground tissue is dull red or reddish yellow. A vertical section shows this zone completely surrounding the base of the stem, extending upwards as a solid band of reddened tissue to about half its height and then breaking into long streaks. In roots the visible effect is confined to the cortex which becomes dry, flaky and reddish brown in colour.

The parasite is a nematode named *Aphelenchus cocophilus*. The adults are about 1 mm long. The eggs are cylindrical and slightly curved and are deposited in the living tissue. The scattered red dots which mark the extension of the red zone in the stem and the beginning of infestation in the leaf stalk are initial nests containing usually a few adult worms together with larvae and eggs. The red zone in the stem has a dense infestation of myriads of active worms. They are also found on the white meristem of the upper extremities of the stem and of the embryonic leaves. In roots the worms are present in large numbers but eggs are rarely found.

The infection probably takes place at the base of the leaves. It is believed that the worms ascend from the soil by way of the surface of the stems and gain entrance at the base of the leaves. This is known to occur in the nematode diseases of rice and black currant.

Control

When a tree dies, the soil in the neighbourhood becomes heavily infested with the parasite. Hence, affected trees should be cut down, the roots gathered and the whole lot burnt. Digging of isolation trenches to check the spread of the nematodes from palm to palm controls the disease to a certain extent. Since nematodes are highly resistant to chemical poisons, soil disinfection is not efficient. Based on the theory that the worms travel on the outside of the stem it is considered possible that a band of crude oil on the stem may hinder their ascent.

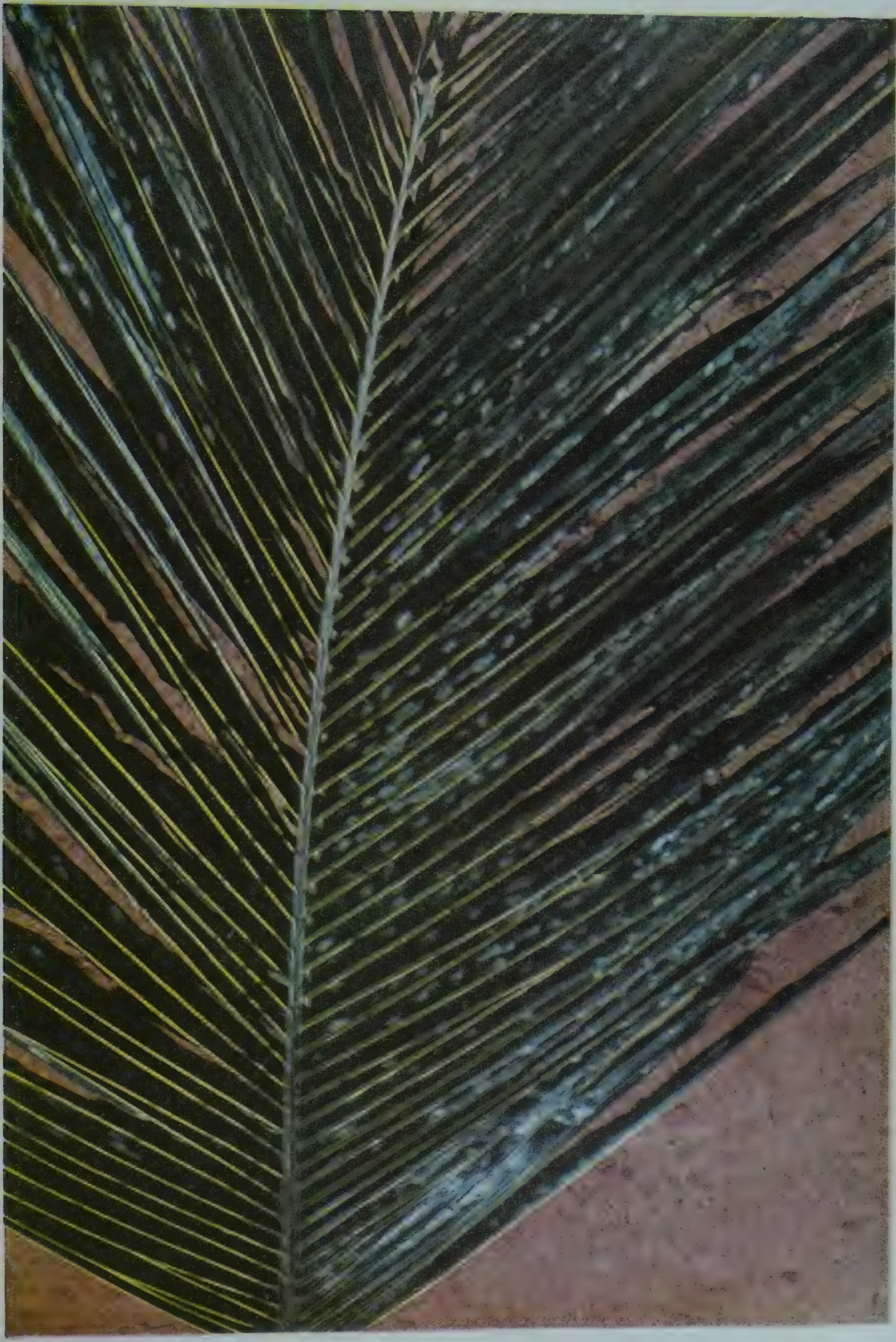
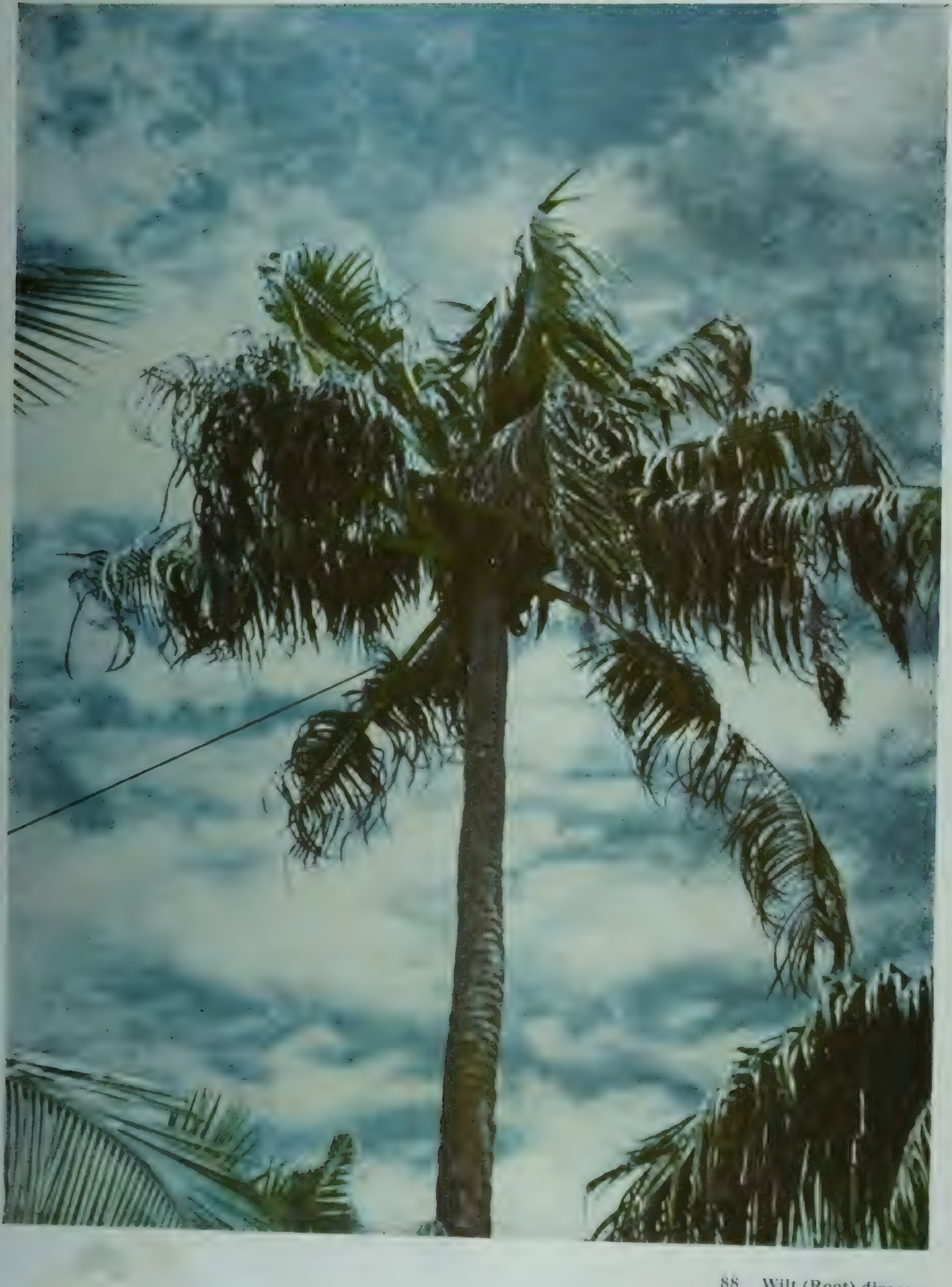


Fig. 87. Leaf blight



88. Wilt (Root) disease

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CHAPTER XIII

SOIL CONDITIONS IN RELATION TO HEALTH AND DISEASE

Although the coconut palm is exceptionally tolerant to adverse environments, it is nevertheless subjected to several maladies, some of which often prove fatal and cause enormous financial losses to the grower. The different diseases of the coconut palm have been discussed in the previous chapter. It may be seen that the disease conditions of the palm may be caused by purely pathological agencies like fungus, bacteria or virus, or by purely physiological agencies such as soil deficiencies or deranged metabolism. In general, whether the cause of a particular disease is parasitic or nutritional, the conditions may be directly or often indirectly related to different soil factors. Considerable attention has been devoted to these aspects and some of them are described below.

When a plant is growing under ideal soil and climatic conditions, it may naturally be in a position to offer resistance to the diseases. Thus, in suggesting control and prophylactic measures, primary importance has to be attached to providing the plant with good environmental conditions for optimum growth and consequent capacity for disease resistance. When a disease is definitely associated with a weakly pathogenic organism, its effect could only be a secondary one, the primary and predisposing cause being a soil or climatic factor.

Among the different common maladies recognised in coconut, some like bud-rot, leaf-rot, etc., are definitely known to be purely parasitic; some like the bronze leaf wilt and the tapering or pencil point condition are believed to be due to unsuitable soil conditions while others such as stem bleeding and fungal root-rots are known to be associated with parasitic attacks predisposed by soil conditions.

Soil conditions as related to wilt diseases

Commenting in general on the wilt diseases of the coconut with particular reference to the ' Bronze leaf wilt,' Briton Jones (1928, 1929, 1940) states that whether or not an organism is associated with the disease is not known but his observations in Trinidad and St. Lucia, suggest very strongly that the *prima causa* is a soil factor. The very definite correlation between lack of drainage in coconut soils and the incidence of the disease, indicates that an organism, if there is one, is secondary. The soil moisture factor is to a large extent, dependent on the tilth, texture, humus content, etc., of the soil, together with unsuitable and in many cases, definitely injurious agricultural operations.

The trouble might be described as ' physiological drought ' since it occurs on badly drained land and on land subject to desiccation during the dry season. Excessive soil moisture and too little moisture have the same physiological effect, on the coconut palm. Shepherd (1927) has independently expressed the same views in regard to a disease of coconut palms in Mauritius. He wrote that the unhealthy appearance of coconut palms at Pointe aux Sables, is attributed to the water-logged condition of the soil in some areas and to a deficiency of water in others, rather than to the presence of any specific organisms. Inoculation tests with fungi isolated from diseased coconut roots (species of *Botryodiplodia* and *Chaetostroma*) have given negative results. Drought, according to these authors, causes desiccation of soil to such an extent that any moisture which is left is almost entirely unavailable to the plant. There is also the possibility that prolonged water-logging could bring about the same result. A similar observation was made by Menon *et al.* (1952) in India with regard to the root infection caused by *R. solani*, *R. bataticola* and *B. theobromae* on coconut seedlings. The fact that such infections are worse in the low-lying areas which are badly drained and on lands with permanent water table about four feet or so below the surface of the soil, suggests that water-logging, might have some direct connection with root infection. In Trinidad, according to Briton Jones (1940) severe disease symptoms are observed in some areas on high sloping ground with no water table within several feet of the surface. The soils on which the bronze leaf wilt is prominent in Trinidad are rather heavy and dry out rapidly and crack in the dry season. This has a deleterious effect upon the root system and might be responsible for the disease. He also lays emphasis on the suitability of land for coconut cultivation before planting programmes are chalked out. Altson (1924, 1925) even attributed bud-rot in British Guiana to unfavourable soil conditions whose deleterious effects have in many instances been aggravated by cultural neglect. The selection of areas for planting coconuts seems often to have been made without due regard to their requirements. He found that the root affected areas were those situated either in low-lying, badly drained, heavy clay front lands or on ' pegass ' soils which suffer from similar disabilities.

With regard to bronze leaf wilt, Bain (1934) has also emphasised unsatisfactory conditions of water supply within the tissues of the palm. Recently, Martyn (1955) described the occurrence in Southern Nigeria of bronze leaf wilt disease on coconuts which has thrown a new light on the problem. The disease was observed on friable porous sand to sandy clay of very considerable depth and in a rainfall forest zone. He accordingly rules out all the earlier suggestions of the disease being caused by unfavourable conditions of the soil, due to heavy clay, impervious subsoil, high water table or rapidly drying sand. He states further that a coconut plantation wiped out by the disease and remaining fallow for some time and then replanted with coconuts has recently been again the victim of the epidemic, palms aged 20 years or more being killed. This behaviour which has had its counter-part in the West Indies does not suggest the presence of any residual parasite which might have affected the new planting earlier. However, no parasitic organism was found associated with the bronze leaf wilt, and the evidence so far points to a causal factor as one related to the nutrient uptake. The occurrence of what is apparently the same disease in such varying soil types as those of West Africa and of West Indies and Guiana suggests that more complex factors than the lack of a specific element are concerned.

The usual onset of the disease when the palms are in full bearing indicates that the requirements of fruiting are in some way involved. The ' unknown disease ' of the coconut palm also occurs on a very wide range of soils in the Caribbean which again rules out according to Martyn (1949), a simple minor element deficiency as the cause, but no parasite has been found and if the disease is due to a virus, the symptoms are unique for the virus disease and the habits of the vector are unusual. In another paper Martyn (1954) has stated that the symptoms of Cape St. Paul wilt in the Gold Coast and of a similar disease in Nigeria appear to be identical to the bronze leaf wilt of Trinidad and British Guiana. Investigations and observations he made at Keta failed to reveal any pathogen consistently associated with diseased palms and point to the cause being physiological. However, there was no deficiency of any major nutrient or any trouble due to ground water table, soil structure, or toxic accumulations of chlorides or other elements and suggests the deficiency of one or more of the micro-nutrients. Further puzzling features about this disease are slight differences in its behaviour both in different areas of Jamaica observed earlier by him (Martyn, 1945, 1949) and in its appearance in Haiti and Nassau as described by Leach (1946).

In a private communication, the Director of Agriculture, Gold Coast (1956) has stated that in recent years, the menace of a disease of the coconut palms known as bronze leaf wilt in the Keta area has been observed. Investigations carried out on this disease failed to reveal any associated pathogen, and trials involving the use of fertilisers, farmyard manure, trace elements and various cultural practices also were not successful in controlling it. Salinity readings of the ground water measured as total chlorides showed palms to be growing in water containing as much as 12,000 ppm and revealed that the disease was epidemic in areas of both high and low salinity. According to Huggins (1930), who reported on the wilting of coconuts in British Guiana, comparable to the bronze leaf wilt in Trinidad, the contributory factors to the occurrence of the disease are insufficient nutrient supply, water-logging and poor cultivation in general. He noticed the disease on heavy soils and occasionally on sand reefs. Edwards (1934) writing on the health of coconuts in Jamaica describes poor soil conditions as the cause of the susceptibility of the coconut palms to diseases. He ascribes this to unsuitable soil environments and lack of soil cultivation.

In his account of a serious outbreak of disease on coconuts in Puttalam in Ceylon, the symptoms of which corresponded very closely to those of the bronze leaf wilt in Trinidad, Park (1932) states that all evidence collected locally pointed to the condition having been brought about by the severe drought which had prevailed in the region during the preceding six months, only 8·6 cm of rain having been received as against the usual average of 20·6 cm. The disease was worse on poorly cultivated land and on land which in wet weather becomes water-logged and swampy. Improvement of soil tilth by the addition of organic matter, drainage of low lying lands to improve root development and thus to increase the resistance of the palm to drought conditions are according to Park, beneficial.

Bain (1934, 1937) in an endeavour to correlate soil factors with the occurrence of bronze leaf wilt examined soils from wilt and wilt free areas from estates scattered throughout Trinidad for texture, reaction, organic matter, nitrogen content, carbon/nitrogen ratio, available potassium and available phosphate. He concluded that the physical conditions and allied water relationships of the soil are of prime concern.

He also brought out the importance of root growth restriction in the affected areas as compared to healthy areas. Sankarasubramoney *et al.* (1954) have carried out the same type of work with regard to the root and leaf diseases of the coconut palm in Travancore-Cochin and their results are in general agreement with those of Bain. Even though Bain and Briton Jones disagree in the matter of the methods of ameliorating the soil conditions, both believe that an alternative crop is the only suitable solution. Such a practice will be rather revolutionary if it is to be adopted in a country like India.

There is thus quite a good deal of support to the opinion that the trouble in the wilt conditions is definitely below ground and that it is due to a factor or combination of factors which interferes with the functions of the conducting system. This is indicated by the regularity with which the wilting of the leaves progresses in the order of age, the lowest leaf being in a more advanced stage of wilting than the one next above it and so on (Briton Jones, 1940). Sharples (1926) has stated that measures designed to improve and ameliorate the soil conditions should always have to be undertaken in conjunction with sanitation methods. One method suggested has been the application of lime and fish manure mixture which brought about definite improvement in twelve to eighteen months time.

Pandalai *et al.* (1954) reported an interesting instance of sudden wilting of coconut palms as a result of changed (unfavourable) conditions in the soil. The wilting of the palms in this instance appeared to be due to the root injury as a result of changes in the soil conditions caused by (1) the shift in pH due to the percolation of the subsoil water on the surface of the soil during the process of dumping of the dredged subsoil on it, (2) the presence in the water of readily oxidisable agents such as sulphides, ferrous iron, etc., the presence of toxic factors such as soluble aluminium, (3) the potential capacity of the dredged subsoil for the formation of mineral acids by hydrolytic changes as well as (4) complete anaerobic condition in the root rhizosphere causing intense root suffocation. Here is an instance of wilting due to purely physiological causes (Figs. **89** to **92**).

Bud-rot

The *Phytophthora* bud-rot of the coconut palm has been reported from several coconut growing countries (Horne, 1908, Ashby, 1918, McRae, 1923, Dowson, 1924).

The environmental conditions prevailing where bud-rot has been recorded have many features in common with those obtaining in areas where the other disease conditions of the coconut palm have been observed. In a typical soil profile of an affected area, it is found that there are proportionately large areas with very compact, almost impermeable hard pan or clay layers present, which hold the water at the surface and restrict root growth. In certain flat areas where loss of palms, leaf fall and nut-fall were most in evidence, a stiff clay band was present usually at a depth of 15 cm to 23 cm. A superimposed water table appears to exist in such areas during the wet season. The evaporation of surface water continuously adds to the humidity of the surrounding atmosphere.

Tapering disease

Furtado (1923) found tapering of coconut palms in Akyab in Burma to be associated with lack of drainage in neglected situations which was liable to flooding during the rains. Teodoro (1925) stated that in the Philippines, the narrowing of the trunks of the coconut palms immediately below the crown was probably caused by malnutrition. Vandenburg (1927) described a disease in Guam known as 'Tinangaja', the symptoms of which resembled tapering stem, which Briton Jones (1928) called tapering stem wilt. Dwyer (1937) has referred to tapering stem in New Guinea and classes it as a deficiency disease. Ocfemia (1937) is inclined to believe that 'cadang cadang' of the Philippine islands is a virus disease although its symptoms resemble tapering stem disease. The tendency is to group all these cases under the heading 'starvation' as a possible cause. Similar conditions are noticed in several islands of the British West Indies. Cooke (1950) in Ceylon has described the condition characterised by withering of the older leaves, the reduction in the size of the crown and 'pencilling' and considered it to be due to nutritional factors. He distinguishes 'slow tapering' which appears to be caused by soil exhaustion, soil hardening or water-logging, and 'quick tapering' which is attributed to deficiency conditions. The same is believed to be the cause of the St. Mary disease observed in Jamaica described by Martyn (1945) and 'Maturation wilt' in New Guinea (Dwyer, 1937). Pencil point or tapering stem has been observed in Travancore-Cochin especially on the coastal sandy areas which are particularly liable to be permanently water-logged such as on certain bunds and low-lying areas. The tapering of the stem is very gradual and likewise the diminution in the size of leaves and nuts progress rather slowly. The leaves slowly and gradually change in colour and are infected by *Pestalotia palmarum* and *Diplodia* sp. In these cases the soil has been found to be poor in organic matter and inorganic food materials. The yellowing of the leaf tips appear to be similar to the symptoms presented by several other palms grown on potash deficient soils. Briton Jones (1940) is of the view that application of a complete fertiliser mixture will help recovery of the palms. It may be mentioned that unless soil amelioration is carried out much before the tendency to tapering has taken a definite hold, there are few chances of the palms getting recovered.

Red ring disease

Nowell (1919 to 1924) has described a serious condition called Red ring disease of the coconut palm in the Lesser Antilles and has connected it with eelworm infection. He showed that the disease is transmissible to healthy palms. The disease occurs on widely different types of soil varying in texture from sand to heavy clays, but no critical data are available which make it possible to decide whether the disease is more serious on one type of soil than on another. Regular cultivation and manuring of the soil have been shown to be helpful for a certain amount of control. The amount and ratio of the mixture of fertilisers would vary with different soils, but 2·5 kg per palm of a mixture of 200 kg of sulphate of ammonia, 100 kg of sulphate of potash and 200 kg of super phosphate has been suggested, except on light sandy soil where 50 per cent more of sulphate of potash would be required. This would certainly stimulate the young palms to more rapid growth and in at least a number of cases would effectively change the microflora of the treated soil. The treatment is to be continued every year for 4 years. Even though the leguminous cover crops will be definitely advantageous, cultivation of these has not been recommended on the ground of expense and also due to the doubt of the efficiency of the cover crops under tropical conditions. It may, however, be seen that the principle of these recommendations is that the palms in the susceptible stage of their growth, viz., 4th to 7th year of the planting are rendered healthy, so that resistance to disease is acquired and the infection checked.

Stem bleeding

The stem bleeding disease of the coconut palm described in several parts of the world and accepted to be caused by the organism *Ceratostomella paradoxa* presents some interest to the soil aspects in relation to disease conditions of the coconut palm. The disease is believed to be caused by infection through the growth cracks on the stem which are vulnerable to the fungus. The occurrence of growth cracks in different plants in many parts of the world has been connected with strongly marked alteration of the wet and dry seasons. This has been connected again to the drastic and sudden changes in moisture contents of the soil. Thus, any measure which tends to level out the soil moisture curve or in other words tend to avoid excessive drying out, wetness or water-logging of the soil, will reduce the number and extent of growth cracks. To sum up, good soil husbandry could effectively check the incidence of stem bleeding in palms. Sampson (1923) has described an instance in which lack of soil drainage had aggravated a condition of stem bleeding of palms. Petch (1909) in Ceylon has made observations to test the validity of opinions which have been expressed to the effect that the disease was due to the effect of artificial manures applied to the soil. Against this is the fact that the disease is found extensively in plantations in which no manure has been used, in another, manured only with cattle manure, and in a third, manured with artificial manure. There was the view that the disease was due to unsuitable soil but Petch observed the disease on swampy, rocky and on typical coconut soils. The distance of coconut plantations from the sea was also stated to have no influence since it was found in gardens very near the sea in the Negombo district and in gardens at higher altitude inland near Mirigama and in Dumbara. These showed that elevation was without any effect. Petch concludes that " environmental factors appear to be altogether outside the question ". With most of these views Briton Jones is not in favour and is of the opinion that a system of drainage, cultivation and manuring may give excellent results in every way. The latter depends to some extent on the soil type and the ameliorative methods should be worked out to suit the soil conditions of the locality. Indeed, the attempt should be to avoid all drastic changes of soil moisture and other conditions and to keep the palms permanently as near as possible to the optimum for continued and rapid growth.

Root disease

This condition has been reported from several parts of the coconut growing countries. Muller (1934) stated that extensive areas of coconut palms in West Borneo where the water table is too high were found to be attacked by *Polyporus sp.* and that root rots were mainly found where soil conditions are not suited to coconuts. It is said that in the Philippines, the root diseases are common in water-logged soil but that the primary cause of the rotting may be due to lack of root aeration. A similar observation was made by Menon *et al.* (1952) in India with regard to the root infection caused by *R. solani*, *R. bataticola* and *B. theobromae* on the coconut seedlings. The fact that such infections are worse in the low-lying areas which are badly drained and on lands with permanent water table about four feet or so below the surface of the soil suggests that water-logging might be correlated with the infection of the roots. These aspects receive some support from the results of infection experiments carried out by Menon *et al.*

Park (1928) has put forward the view that the *Rhizoctonia* infections of the root of coconut in Ceylon is dependant on the host parasite relationship, and that the mycorrhizal existence of the fungus may be transformed into pathogenic infection when the symbiotic relationship is upset due to unfavourable conditions predisposing the palm to the disease. Petch (1909) and Bryce (1924) have advocated sanitary measures for ameliorating the soil conditions. However, as against the sanitary measures recommended by Petch, Bryce, Briton Jones (1940) and De Jong (1933) believe that amelioration of soil conditions so as to render impossible the establishment of parasitic relationship between the plant and the parasite, even though the latter may be present, should be aimed at. Effective drainage of the land used and liming are in this connection important. Affecting the same fundamental principles of plant growth is the rectification of soil deficiencies of which potash ranks as one of the most important. Dwyer (1937) has also given expression to the same view-point and writes that there is more decided room for investigations as to what conditions, particularly soil conditions are injurious or beneficial to the palm. The important role of the soil environment in the incidence and severity of these root diseases cannot be over emphasised. The root infecting fungi whether a soil inhabitant or a soil invader (Garrett, 1956) are influenced to a great extent by environmental conditions in the immediate zone of its existence. Dealing with complex relationships among plant roots, parasitic fungi and soil micro-organisms, he has reviewed the possibilities of regulating the microbial balance between the parasitic and saprophytic micro-organisms in soils through the introduction of various kinds of organic matter, nitrogen fertilisers and liming materials. These with several other aspects have to be considered in planning disease control. For the coconut palm, sanitation and certain palliative measures may offer the best possibilities.

Leaf diseases

The different leaf diseases of the coconut palm described in different areas are known to be parasitic and they have not been ascribed directly or indirectly to soil conditions. It may however, not be impossible that unsuitable soil conditions and unbalanced nutrition predispose the onset of parasitic attack in the case of leaf and root.

Nut-fall

McDonald (1924) reported a disease of coconut fruits causing a splitting of the husk and accompanied by exudation of gum in the coastal districts of Kenya and attributed this to the unfavourable soil conditions during the dry spell. The disease has also been associated with *Colletotrichum* sp. in Kenya. Welsford (1926) gave an account of a disease occurring in Zanzibar where he found that a small crop of coconut was associated with excessive fall of the young nuts and more especially with the condition known as gumming which was widespread throughout the island. This has also been reported by Dupont (1927) to occur in the Seychelles and by Teodoro (1925) in the Philippines. This disease has not been connected with any parasitic fungi and Welsford suggested malnutrition to be the cause of the trouble. The conditions of aeration of the soil appeared to be an important contributory factor. Some NPK manuring was carried out as a remedy. It has also been reported that the premature fall of coconuts may be due to physiological factors produced by inadequate soil moisture or possibly to a fungus disease active in wet weather.

Nut-fall related to soil conditions

Premature fall of nuts is considered to be caused by physiological factors resulting from conditions such as excessive moisture, inadequate moisture, water-logging or the deficiency of any of the major nutrients. Stockdale (1921) has described the serious nut-fall in Ceylon under excessive rainfall in heavy soils in the Kurunegala District and under excessive and continuous spells of wet weather, the damage was considerable. Gadd (1923) stated that in Ceylon it was shown that water deficit following a prolonged drought caused greatly increased fall of the female flowers or buttons. Such abscission of buttons and young fruits may be caused by periods of drought, as may the falling of large nuts, on clay soils which become hard during the dry weather with a tendency to water-logging in periods of excessive rainfall. These particular soil conditions during heavy rains become deleterious to the healthy growth of the root system by interfering with the air supply which, despite the excess of moisture present, leads to reduced absorption of water and untimely death of the roots resulting in nut-fall. In this connection Tammes (1937) observed " it seems that the number of fruits produced is not limited by the number of flowers nor by pollination but is exclusively controlled by the physiological condition of the nutrition of the tree ". As a result of his studies at the Coconut Experimental Station at Manado, Celebes, he concluded that a very important factor is the available quantity of water. Thus it is seen that water relationship leading to physiological drought is no doubt an important soil condition orientating nut-fall. Dwyer (1937) has discussed the chances of soil conditions in certain cases to be associated with insect attack, such as of the spathe borer as the chief causal agency for nut-fall in New Guinea. Pagden and Lever (1935) are of the opinion that the cause of nonbearing or of immature nut-fall is more probably due to unsuitable conditions of the soil and rainfall than to insect attack. In the British Solomon Islands and New Guinea where premature nut-fall is so common, Dwyer is also of the view that it is largely associated with unfavourable soil conditions. Other workers have however, given evidence which definitely associates premature nut-fall with the activity of *Phytophthora* as well as *Botryodiplodia theobromae* and among them are Sundararaman and Ramakrishnan (1924), Simmonds (1922) and Teodoro (1925). Bordeaux mixture was used by Teodoro with success to spray the bunches of nuts to prevent nut-fall after the nuts are set.

In both temperate and tropical zones, application of nitrogenous manures has helped proper setting and ripening of fruit. Thus Gadd (1923) cites the observations made in Indo-China where shedding of buttons considered to be caused by nutrient deficiency in the soil was remedied by the application of nitrogenous manures. However the same author reported that similar treatment was not helpful in Ceylon, where fertiliser application indeed increased the total crop, not by reducing button shedding but rather by increasing the initial number of female flowers. Soil conditions and the prevailing as well as the preceding weather conditions orientate the setting of nuts. It should be expected that soil deficiency conditions should be acute in tropical countries which receive heavy rainfall and consequently suffer losses of mineral nutrients by leaching. In several areas under coconut in different countries, where the plantations were long in existence and cropping went on continuously for years, there should be decided soil exhaustion. Lever (1935) for instance referring to the British Solomon Islands states that soils such as are not uncommon in the protectorate have by repeated cropping had their available nutrient reserves reduced to a minimum for plant growth and are thus said to be exhausted. The continued growth of almost any crop leads to exhaustion of the soil so that measures have to be taken from time to time to make good the losses sustained by the soil.

Foliar yellowing

Chlorotic conditions in which the production of the green colouring matter in the leaves is very much impaired are often the result of soil deficiency. This is probably what happens during the monsoons when palms show a general foliar yellowing. Results obtained (Menon, 1956) appear to show that this foliar yellowing is a potash deficiency symptom. There is evidence (Bolle Jones, 1955) that potassium is able to cure vein chlorosis. The better production of chlorophyll, induced by added potassium, is achieved by an increase in the organic acid content, which is known to influence tissue pH and increase iron utilisation. Martyn (1945) has described instances in Jamaica of foliar yellowing due to water-logging in permanently wet sites or clay soils as also of yellowing due to drought conditions.

Reinking (1950) has reported the symptoms of a soil deficiency trouble in the Philippines causing the general yellowing of the older living leaves and an abnormal number of browned dead leaves to hang around the trunk. Foliar yellowing is more visible in old plantations. Under such conditions, the vitality of the palms is reduced and their capacity for disease resistance lowered. Hansen (1952) remarks that the "unknown disease" in the West Indies is neither infectious nor due to nutrient deficiency but is due to toxic soil conditions. He states that similar symptoms could be produced on coconut palms by poisoning them with small concentrations of salts like cadmium or strontium chloride. Recently Cassidy (1951) has suggested that a number of disease conditions of the coconut which have been described as separate entities may be only due to salt damage. The factual evidence upon which all workers are fairly well agreed has either the characteristics of salinity or could most readily be explained on such a hypothesis. The facts that different disease conditions are to be found in trees in all soil types, low-lying or elevated, coastal or inland, manured or unmanured point to the conclusion that salt injury, especially from the subsoil water or from the proximity to the sea cannot be the cause of the diseases under reference. A physiological condition of some palms is reported from New Ireland designated as ' maturation wilt ' in which the symptoms appear when the palms just come into bearing, which usually is a critical period in the life of the palms. In the absence of any parasitic attack in the roots, it was traced to a potash deficiency in the soil.

Again, the soft leathery kernel of the coconuts found in the Bismark Archipelago according to Dwyer (1937) has probable connection with soil impoverishment. Dwyer with his wide experience of coconut palms in health and disease in New Guinea has stressed that where the vigour of coconut palms is lowered, by any cause whatsoever, such as drought, unsuitable soil conditions, soil exhaustion or insect troubles, the palms are rendered liable to serious attack from fungi which are normally only very weakly parasitic.

Several other diseases and derangements of the coconut palm are also due to primarily unsuitable soil conditions but in some cases, complicated by secondary fungal and insect attacks. Among these are ' seasonal bearing ', ' leaf droop ', ' frond choke ', certain types of ' nut fall ', ' end collapse ', ' deficiency spotting ' and ' die-back '. Mesa Bernal (1951) writing on coconut diseases called ' dwarfing of the leaf ', ' little leaf ' and ' porroca ' at Columbia, mentions that those conditions are ameliorated by the introduction of cattle grazing in a plantation with a forage cover crop. The disease is serious in the sandy coastal region of Tolu. Copper fungicides have been used with success in controlling them. Soils which are deficient in mineral nutrients, organic matter and moisture supply favour disease incidence. He is of the opinion that boron and zinc deficiency investigations may give indications for profitable control. Such studies with boron, copper, manganese, and zinc fed to the soil, at the root regions, trunk injections and depositing small cloth bags containing these salts in the crown were actually made by him. Mesa Bernal (1954) describes a diseased condition mostly affecting nuts which he ascribes to soil conditions such as excessive soil humidity, fungal infection and soil salinity combined with a high water table or to the presence of toxic alkaline salts. Analysis of soil from the affected regions showed high manganese and low magnesium content even though the symptoms were not those of magnesium deficiency. Meiffren (1951) is of the opinion that a disease he observed in Togo, induced by *Fusarium oxysporum* appear to be brought about by a shortage of phosphoric acid especially where potash is high; in other words, due to a disturbance in the potassium/phosphorous ratio in the soils. The need for the extensive chemical and botanical research on the nutrition of the coconut palm in relation to the soil conditions is thus quite obvious. This also points out the urgent need for cultural practices designed to keep up the vigour of the palms and remedy unfavourable environmental conditions as imperative factors in disease control. Butler (1908) has stressed the importance of cultivation and manuring of neglected coconut gardens. He is of the opinion that the general health of the palms has deteriorated due to neglected drainage, weed growth, etc. Better soil conditions according to him should improve health and therefore impart disease resistance to the palms.

The root and leaf diseases in Travancore-Cochin

In Travancore-Cochin (Kerala), Varghese (1934) and Menon (1946-54) have carried out extensive investigations on the soil conditions in relation to the root and leaf diseases of the coconut palm. They collected comparative data on the nutrient status of the soil of healthy and diseased areas. The soil samples were examined for their total nitrogen, phosphoric acid, potash, lime, magnesia, ferric oxide, available phosphoric acid, available potash, organic carbon, organic matter, loss on ignition, combined water and hygroscopic moisture. The carbon/nitrogen ratio, mechanical composition, base exchange and pH values, have also been determined. Statistical examination of the data obtained has revealed that there are significant differences between the soils of healthy and diseased areas in the following factors :—

(1) The available potassium was lower in diseased areas as compared to healthy ones.
(2) Total calcium was lower in diseased areas.
(3) Values for (*a*) total exchangeable bases and (*b*) percentage base saturation were lower and (*c*) exchangeable hydrogen was higher in diseased areas.
(4) pH values were lower in the diseased areas as compared with those of healthy ones.
(5) Iron content was lower in diseased areas and
(6) A large proportion of the localities in the diseased group had water table or some impermeable layer near the surface.

The disease was found in all the soil types. This makes it improbable for the mechanical composition of the soils to have any direct bearing on the disease aspects. It would thus be seen that certain common features in all the soils contribute to the predisposing conditions for the disease. Among the factors mentioned above, the first five may be considered to be more or less inter-connected, although individually they may be influencing the health of the palm. Lack of calcium and potassium in the soil will naturally mean that the exchange complex of the soils is unsaturated. This will give a low value for total exchangeable bases and percentage base saturation and a correspondingly high value for exchangeable hydrogen. An unsaturated soil from this point of view will be naturally having an acid reaction.

Again, water-logging often leads to anaerobic decomposition of organic matter in the soil. This, combined with a deficiency of base, will cause increased concentration of organic acids, which in their turn, further increase soil acidity. Each of these factors has got its own individual effects upon the palms and these effects may be direct as well as indirect.

Thus a deficiency of potassium in the soil may directly affect the palm by its injurious effects upon the root system and by lack of regulation of the water conditions within the plant as well as water losses by transpiration. It is a well-known fact that plants deficient in potassium will not be able to withstand drought conditions. Indirectly potash deficiency may affect the palms by reducing their resistance and making them more susceptible to diseases and pests. Certain plant diseases have been controlled by the application of potassic fertilisers. This should particularly apply to the coconut palm whose potash needs are great and in the physiology of which the role of potassium is important. Menon *et al.* (1952) have stated that the pathogenicity of *R. bataticola* to the coconut palm under potash deficient conditions may be one of the many factors accentuating the root disease of the coconut palms. Several workers, have demonstrated that the relationship between potash deficiency and parasitism is especially pronounced in perennial plants. The faculty for replacing injured or diseased roots is of importance in the root disease of the coconut palm, since so long as the fungal pathogen confines itself to the roots, it is possible for the palm to go on replacing affected roots provided environmental conditions are favourable to their replacement. These considerations emphasise that soil conditions materially orientate health and disease aspects of the coconut palm.

A deficiency of calcium might render the cell walls thin and permeable, affecting to some extent the osmo-regulations in the cells and also by reducing the activity of growing points, especially root tips. Indirectly it may affect the trees growing on them by producing acid conditions in the soil. This enables the release of soluble manganese and aluminium which may exert toxic effects on the plants. A condition of wilting due to aluminium toxicity has been described by Pandalai *et al.* (1954). They also discuss the different aspects centering around the possibility of the soil being rendered acidic due to the formation of mineral acids in the subsoil on account of hydrolytic changes. A lack of calcium may also lead to poor tilth of the soil concerned, as well as adversely affect the activities of certain beneficial soil micro-organisms.

The effect of soil pH

The direct effects of the low pH value may occur due to the contact of the roots with the subsoil water having an acid reaction. But most of the effects of a low pH value on the plant are rather indirect. It is said to adversely affect the availability of phosphorus to the plant.

Micro-nutrients in relation to the disease

Apart from the physical conditions of the soil such as water-logging as well as deficiency of major plant food factors, it has been shown that certain micro-nutrients also appear to orientate health or disease of the coconut palms. It is clear that the results obtained from the analysis of soil and plant material are to be correlated in order that a fuller elucidation and a clearer picture of the problem can be had. It has to be seen whether a particular nutrient deficiency in the soil is also to be found in the leaf and only then can there be any correlation of soil deficiency as affecting ultimately the physiological processes of biosynthesis taking place. Often there may be accumulation of nutrient ions in the different parts of the leaf tissue.

Innes (1949) found no relationship between manganese content of palm leaf tissue and disease incidence. On highly alkaline calcareous clay soils, the presence of much organic matter and fluctuating conditions of soil aeration, and reduction are probably factors causing an adequate uptake of manganese by coconuts. He says that the symptoms are not such as would normally be expected for manganese deficiency. However, Dickey (1942) has stated that manganese deficiency of palms in Florida was cured by foliage spray of palms or soil treatment with manganese. Martyn (1948) discussing the West Indies bud-rot of the palms in Jamaica states that injection of the trees with iron, boron, magnesium and copper had no checking effect, and therefore abandons the soil deficiency theory of the disease. However, liming improved the condition of the palms. It may be that liming helped to release the deficient plant food ingredients in forms available to the palms.

There may be other elements also which may be found in tissues and may not have any detrimental effect on the physiological processes in the leaves. This raises the question of the importance of micro-nutrient elements in the nutritional and physiological aspects of the coconut palm. It may, however, be stated here that some of the micro-nutrients, iron for example, have been able to correct certain conditions of the coconut palm. Bodin (1917) has observed that sulphate of iron does change the chlorotic appearance of the palms and cause their fronds to assume a normal healthy green colour. Probably by some catalytic action the iron sulphate is able to liberate certain of the plant food factors in the soil which caused the chlorotic conditions. Dwyer has also reported in this connection that solid injection of ferric nitrate into chlorotic palms restored their colour gradually. The tonic effect of iron compounds on fruit trees and other plants when applied as dilute aqueous solutions has been experienced in other countries also. It is assumed that in the soil, iron sulphate liberates plant food and directly helps chlorophyll synthesis. Dwyer found that copper sulphate has some definite influence on the chlorotic condition of leaves in New Guinea.

Soil fertility and disease resistance

In many of these diseases it is the influence either of the environment or of some mechanical factor on the coconut that is the essential factor, rather than any organisms which may appear to be related to the diseased condition. In many cases though the environment of the palm may clearly reveal a number of possibly adverse factors, the exact relation between these and the departure from normal growth has not yet been established. This pre-supposes malnutrition as a serious factor in the causal complex. Tissue analysis, and injection trials with both macro and micro-nutrients, etc., would very much help in the maintenance of soil fertility factors, and thereby help in disease control.

It must be stressed that the interaction of many limiting factors comes into play in the causes of physiological disorders of the coconut palm. The genetic constitution of the plant thus for example usually interacts with environment and it is found that weaker palms are much more affected by unfavourable soil and water relationship than strong ones. Our present knowledge on these and related aspects is still in an unsatisfactory condition and much more detailed work as regards the actual physiology and nutrition of the coconut palm through all stages is necessary before complete understanding of the problems is possible.

Sufficient emphasis has been laid on the fact that whether a disease of the coconut palm is due to pathological or physiological causes, soil conditions are to a very large extent the orientating factor. Even the pathogen responsible could get a strong hold in some part of the palm, only when the palm is in unsatisfactory health and therefore with less disease resisting capacity. Soil deficiency factors or the inherent weakness of the palms or both, could be responsible for this state of affairs. Adequate nutrition from a favourable root environment would maintain the palm in a healthy state with greater disease resistance. The old adage ' prevention is better than cure ' applies as much to health of plants as to human health. Maintenance of soil fertility is thus the key to the health and vigour of the coconut palm and the foregoing discussion has shown that this has been uniformly and repeatedly stressed by workers in the different coconut growing countries.

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SUDDEN WILTING

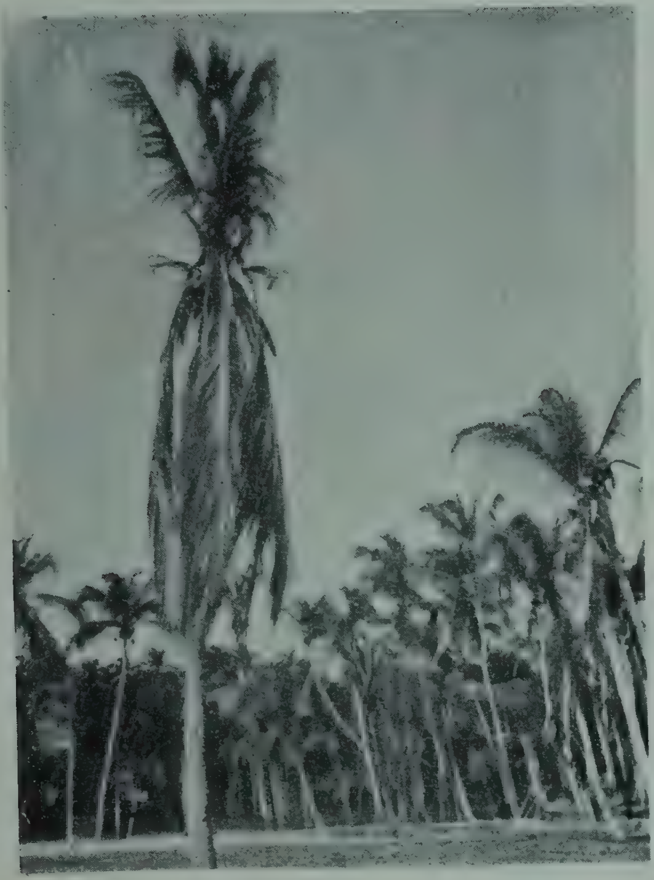


Fig. 89. Sudden wilting — middle stage

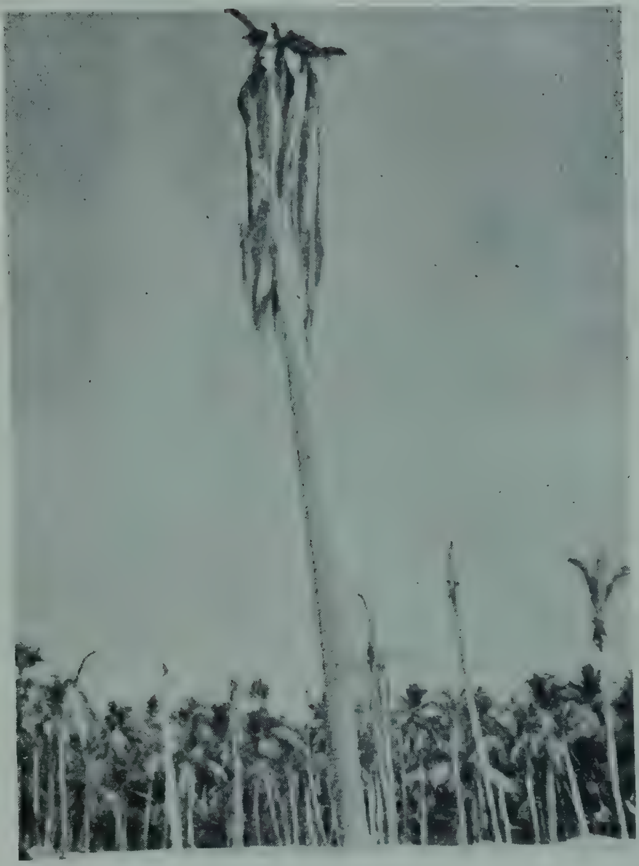


Fig. 90. Sudden wilting — advanced stage

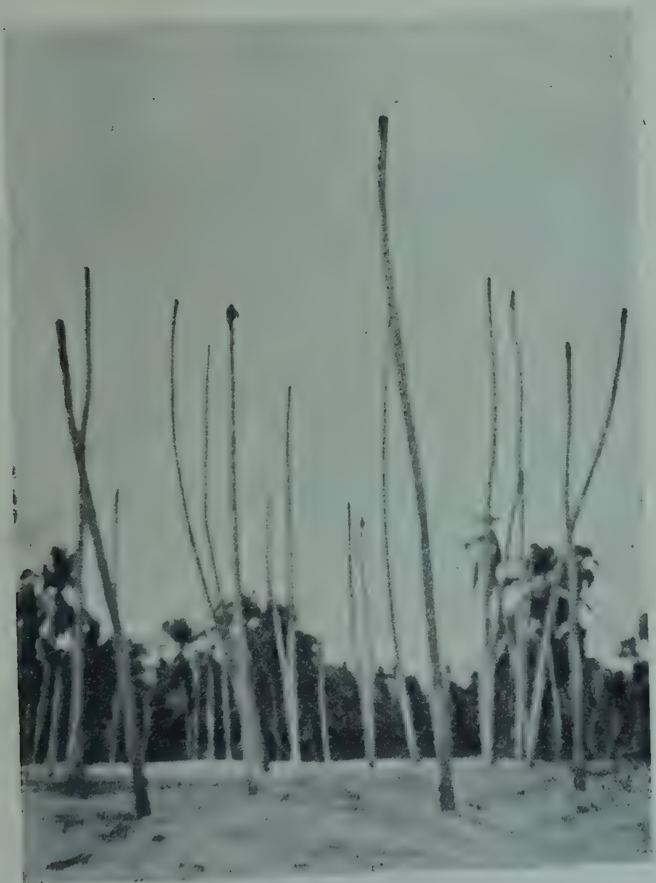


Fig. 91. Sudden wilting — a portion of the devastated area

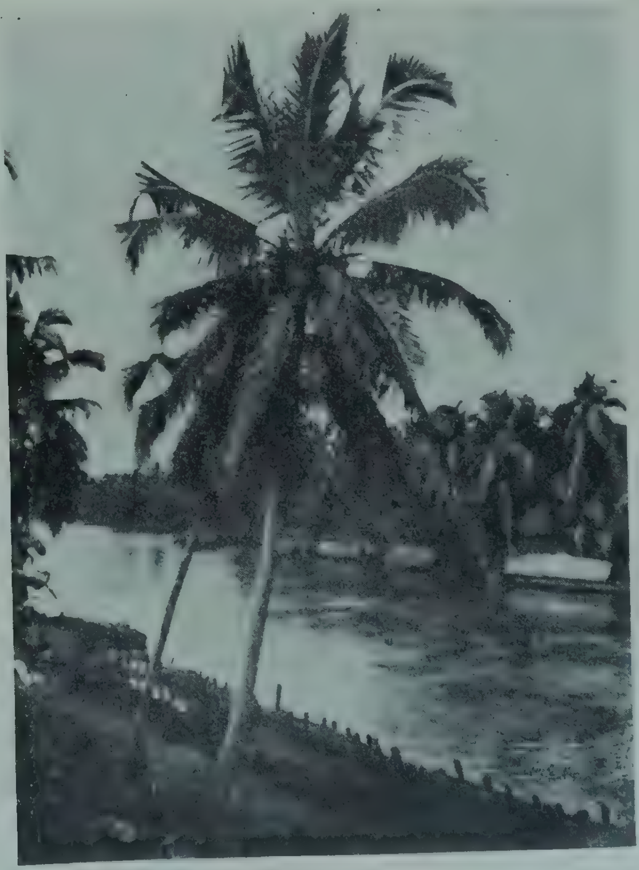


Fig. 92. Healthy palm in an adjacent area

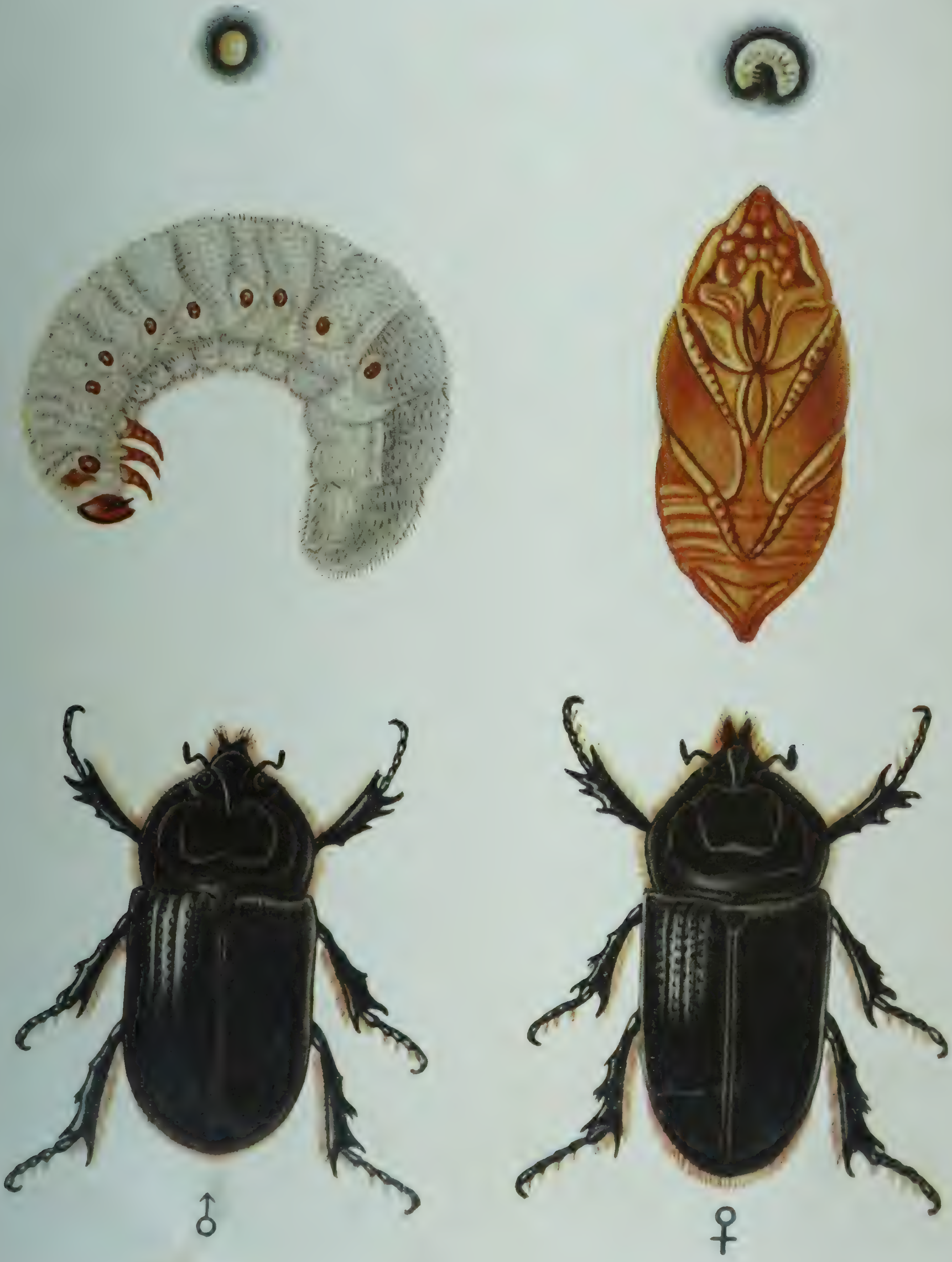


Fig. 93. *Oryctes rhinoceros*

CHAPTER XIV

PESTS

The coconut palm is attacked by a number of insect pests at all stages of its growth. Lepesme (1947) gave a comprehensive list of seven hundred and fifty-one insects associated with the coconut palm. Copeland (1931) has reported one hundred and six insects recorded as pests of the coconut palm, and felt that this list was far from complete. Corbett (1932) published a detailed account of the insects of the coconut palm and furnished the then available data in Malaya concerning the appearance, life cycle and control of seventy-seven insect pests. Evans (1952) listed forty-four insects as pests of coconut palm in the British Commonwealth excluding India and Pakistan. Recently Nirula (1955) recorded one hundred and seven pests which have been reported damaging the coconut palm from time to time.

The pests of coconut palm have a ready supply of abundant food and they can multiply uninterruptedly all the year round with the result that the coconut plantations are often seriously damaged. In 1922, *Nephantis serinopa* Meyr. completely defoliated the palms on the West Coast of India. In 1925 *Levuana iridescens* B.-Bak. devastated the entire coconut plantations in some of the islands of Fiji. Similarly the ravages of *Artona catoxantha* Hamps. in Malaya and Indonesia, *Promecotheca reichi* Baly. in Fiji, *Rhynchophorus* sp. in the Eastern and Western tropics, *Melittomma insulare* Fairm. in Seychelles, *Aspidiotus destructor* Sign. in Fiji, *Amblypelta cocophaga* China in Solomon Islands and *Pseudotheraptus wayi* Brown in Zanzibar and East Africa are quite well known. Recently *Oryctes rhinoceros* L., accidentally introduced into some islands in the South Pacific has threatened a complete collapse of the coconut industry there. The more important pests of coconut according to their natural order are described below.

COLEOPTERA

ORYCTES RHINOCEROS *L.*

The rhinoceros beetle, *Oryctes rhinoceros* L. is one of the major pests of the coconut palm. The adults attack the young, folded leaves, and infested trees receive a serious set-back and may even die. The beetle has been known since very early times in the different palm growing areas of Asia.

In India, it was described during the last decade of the nineteenth century and after that it has been studied by Stebbing (1903), Lefroy (1906), Arrow (1910), Fletcher (1914, 1917 and 1919), Chatterjee (1917), Pillai (1919), Srinivasa Rao (1924), Sen (1920), Furtado (1920), Subramania Iyer (1921), Beeson (1921), Kunhikannan (1923), Ramachandra Rao (1930), Patel (1938), Venkitasubban (1938), Rehman (1940), Cherian and Ananthanarayanan (1939 and 1941), Ayyar (1919 and 1940), Nirula *et al.* (1950, 1951 and 1952) and Nirula (1955). In Ceylon, the rhinoceros beetle has been under investigation by Bryce (1915), Hutson (1922 and 1933), Lester Smith (1936), Johnpulle (1938) and some others. In Malaya, the beetle has been studied by Ridley (1889), Brown (1912), Richards (1915 and 1917), Ponniah (1920) and Corbett (1932 and 1938). The rhinoceros beetle is a serious pest of coconut palm in Burma and has received attention from Shroff (1919) and Ghosh (1923 and 1924). In Indonesia, Leefmans (1920) worked on the life history, habits and control of this pest and published a detailed report. In the Philippines, the work on this beetle has been reported by Banks (1906) and Copeland (1931). In Indo-China some mention about the beetle has been made by Duport (1912), Crevost (1924), Carton (1926) and Caresche (1933). In Formosa, Clausen (1931) recorded the beetle as a pest of sugarcane and coconut palms.

In the Pacific Islands, the beetle was introduced from Ceylon into Samoa in 1909, from where it slowly spread to the rest of the adjoining regions. It has been extensively studied by Gehrmann (1911 and 1913), Jepson (1912 and 1915), Doane (1913), Aulman (1914), Friederichs (1913 and 1919), Swezey (1924 and 1941), Simmonds (1924, 1940, 1941, 1946 and 1949), Dumbleton (1953) and Gressit (1953).

In Africa, a number of different species of the genus *Oryctes* which attack palms occur.

Distribution

The rhinoceros beetle is the most ubiquitous pest of coconut palms. It is presumed to be indigenous to India, Ceylon, Pakistan, Burma, Siam, the Malay Peninsula, Indo-China, Hainan Island, South Africa, Formosa, the Philippines, and Indonesia (Celebes, Ceram and Amboina). Recently it has been introduced into Samoa, Wallis Islands, New Britain, New Ireland, Palau, Tonga, and Fiji in the Pacific.

In India, the beetle is a serious pest of coconut palms throughout Kerala, Madras, Andhra, Orissa, Bombay, Mysore, Bengal, Assam, Andamans, Nicobar and the Laccadive Islands. It has also been reported from Bihar and Hyderabad.

Host plants

Besides coconuts, the rhinoceros beetle is capable of attacking other palms also. The most important of these are the palmyra palm, *Borassus flabellifer*, the toddy or wild date palm, *Phoenix sylvestris* and the African Oil Palm, *Elaeis guineensis*. The other host plants are the date palm, *Phoenix dactylifera*, the areca palm, *Areca catechu*, the sago palm, *Metroxylon sagu*, the nipa palm, *Nipa fruticans*, the sugar palm, *Arenga pinnata*, the fan palm, *Livistona chinensis*, the serdang palm, *Corypha elata*, the talipot palm, *Corypha umbraculifera* and some other ornamental palms. Sometimes it has been reported feeding on agave, sugarcane, pine-apple, tree fern, banana and taro; but these appear to be only accidental hosts. Recently Gressit (1953) has stated that in the Palau islands, the beetle has become a serious pest of the screwpine, *Pandanus* and can maintain its population on this host, from where it has already exterminated the coconut palms.

Description of the pest

The rhinoceros beetle *Oryctes rhinoceros* L., belongs to the Coleopterous suborder Polyphaga, superfamily Scarabaeoidea, family Scarabaeidae, sub-family Dynastinae and the genus *Oryctes*. The species was originally described by Linnaeus (*Syst. Nat. ed.* **10**, 1 : 346, 1758) as *Scarabaeus rhinoceros*.

Egg

The egg when freshly laid is globular, white in colour, but before hatching it changes to dirty white. It is slightly rounded-oval, but not ovate. When freshly laid, it is about 2·5 × 3·5 mm, but during development absorbs moisture until it becomes about 3·5 × 4 mm and nearly rounded. It is fairly hard-shelled, and when dropped on the ground bounces like a table tennis ball.

Larva

The larva, when it freshly emerges from the egg, is yellowish-white in colour and measures about 6 mm to 7 mm in length. The head and the three pairs of legs soon turn brown. When half grown, the colour of the larva changes to dark grey. This colour is partly due to the colour of the food inside the abdomen. The full grown larva is a stout fleshy creature, voraciously feeding all the time. The body is long and somewhat cylindrical, but strongly arched convexly above and concavely beneath, so that the head may touch the caudal end of the body forming a ring. It measures from 75 mm to 125 mm in length and 20 mm to 35 mm in width. The colour of the full grown larva is ash grey and its body is covered with brownish hairs. On the lateral sides are nine pairs of spiracles, one on each side of the pro-thorax and the first eight abdominal segments. Thoracic legs are normally developed.

The larva passes through three instars during its developmental period. The three instars may be distinguished by the size of their head capsules more readily than by their relative body size, as the body grows more or less gradually throughout the larval period.

Before pupation and formation of the cocoon, the larva assumes a dull cream colour, stops feeding and becomes inactive. This inactive stage is known as the prepupal stage.

Pupa

Before pupating, the larvae make cocoons in the soil or in the trunks of palms. In the soil the cocoons are oval, internally smooth, brittle and hard. Their size varies from 50 mm to 90 mm. The cocoons in the palm are made with the chewed fibres, which are cemented together by a secretory product.

The pupa is uniformly brown in colour and is slightly convex dorsally. Its size varies from 50 mm to 70 mm in length and 20 mm to 25 mm in width. The sex of the developing adult can sometimes be made out from the size of the horn on the head.

Adult

The freshly emerged beetle from the pupal shell is light brown in colour and gradually turns into brown and finally into black. The ventral surface of the beetle is reddish-brown. The size of the adult varies from 35 mm to 50 mm in length and 14 mm to 21 mm in width. The head is small but conspicuous, bearing a large, erect, slightly tapering horn. The mandibles are short and strongly toothed. The antennae have highly developed and differentiated lamellate clubs.

The thorax has a large concave area in front and two other pairs of depressed areas situated anteriorly and laterally on both sides of the medial depression. The legs are hairy and well developed. The elytra are finely coriaceously striate lengthwise, and do not cover the abdomen completely. The wings are well developed.

The male beetle can be distinguished from the female by the presence of a longer cephalic horn. The pygidium is densely clothed with reddish-brown hairs in the female (Fig. *93*).

Life history

The beetle lays eggs in the decaying organic matter generally found accumulated in the coconut gardens. When the beetles are abundant, the eggs may be found in isolated lumps of cow-dung, small collection of decaying vegetable matter and sometimes even in the soil below the decaying coconut fronds. These eggs, however, either dry up or even if the larvae hatch out, they soon perish due to lack of food and suitable environment. Normally the eggs are laid only in manure heaps, dying and dead palm trunks, decaying stumps and compost heaps, so that the hatching larva has plenty of food and enough of moisture.

The incubation period of the eggs according to Nirula (1955) varies from eight to fourteen days and on an average lasts ten days on the West Coast of India.

The larva effects its exit from the egg by cutting open the shell. After emergence, the larva rests for a few hours during which period, its integument hardens when it assumes its colour. The larvae feed continuously with short periods of rest. The larval development depends upon a number of factors, the more important of them being temperature, humidity, food and environment. The range of temperature for the development of larvae is from 16°C. to 49°C., the optimum range being 32°C. to 40°C. The moisture content of the food material plays a very important role, the larvae not being able to develop in absolutely dry or water soaked food materials.

The larvae can be found anywhere in the coconut gardens, where there is sufficient quantity of decaying organic matter. The following are the favourite breeding places of the rhinoceros beetle.

(a) *Farm-yard manure.* This is the most favourite breeding medium and any such heap, which has been lying in the coconut growing areas for sometime is most likely to contain a number of developing larvae.

(b) *Compost heaps.* These form extensive breeding grounds, and the coconut plantations round about the municipal refuse dumps are most heavily attacked by the rhinoceros beetle.

(c) *Vegetable decaying matter.* Plantain shoots, grass, fruit and vegetable peelings, etc. when rotting, attract beetles for oviposition in large numbers. Sometimes the larvae may be found in the heaps of coconut leaves lying outside in the rain.

(d) *Dying and dead trunks of coconut.* When the crowns of the palms fall off or when the trunks are cut off and stumps are left standing, they are generally found to be infested with *Oryctes* larvae. Palm trunks are used for a number of purposes in coconut growing areas, and when they start decaying they form material for prolific breeding.

When the decay has set in the living palms due to the red palm weevil attack or due to other reasons like lightning, fire, cyclones, fungal rotting, etc. the beetles may breed in such decaying portions. According to Nirula, the beetle was never observed breeding in healthy tissues of the coconut palms on the West Coast of India. The beetle does not often breed in coir dust or mulched and buried coconut husk. The larval period ranges from 74 to 191 days and on an average is 130 days on the West Coast of India. When the larva is fully mature, it stops feeding and descends to form the pupal cocoon. The cocoon is generally formed deep in the soil, where sufficient moisture is ensured throughout the pupal period. During wet weather, the cocoons may be formed within six inches of the top layer but during dry periods, these may be as deep as four feet. When larvae are feeding in the standing coconut trunks, the pupation takes place inside them, but below the rotting portions, where the tissue has sufficient moisture.

The pupa lies free on its back in the cocoon and is not subjected to any pressure. Immediately on pupation, it is pale yellow ventrally and light yellow dorsally. After some time, the change in colour starts and in 24 hours it assumes its permanent brown colour and its skin hardens. When cocoons are damaged, the pupae quite often die. This is generally what happens on the West Coast during the south-west monsoon, when pupae are killed and consequently after the rains the population of the beetle is at its lowest.

The pupal period varies from 14 to 29 days and on an average is 20 days. The adult after emergence from the pupal shell, remains for 5 to 26 days in the cocoon, before coming out to feed.

The newly emerged adult is very soft and tender, but soon the integument starts hardening and within a week, the beetle assumes its colour and its cuticle hardens.

There is no fixed time for the emergence of the adult from the pupal shell. The emergence from the soil takes place late in the evening, and during the dry weather on the West Coast, a large number of beetles emerge in the evenings of rainy days. The beetles are seen flying about only at night. During the day time, they are either feeding in the crowns of the coconut palm or resting in their breeding places. Their activity begins at dusk and ceases at dawn. The beetle is not capable of extensive flight. The flight range is generally restricted to within 200 yards of its breeding place.

The female beetle starts laying eggs from 20 to 60 days of emergence from the soil and selects any decaying organic matter for this purpose. Oviposition continues throughout the life except for a few days before death. The number of eggs laid varies from 48 to 152, and on an average is 108.

The adult beetle is long lived and has been observed to keep alive from 76 to 219 days in the laboratory cages under conditions prevailing on the West Coast of India.

The sex ratio is nearly equal, with males slightly predominating.

The total duration of life cycle, from the deposition of the egg to the emergence of the adult from the cocoon varies from 101 to 260 days, with an average of about six months. It has been estimated that a single pair of beetles under optimum conditions can theoretically give rise to fifteen million beetles in less than three years (Nirula, 1955).

Parasites and predators

Parasites. *Oryctes rhinoceros* has been reported to be attacked by a number of parasites and predators. Thompson (1943) has described the following five species of Scoliidae as parasitic on *Oryctes rhinoceros.*

(1) *Campsomeris luctuosa* Smith.
(2) *Scolia procer* Ill.
(3) *Scolia azurea* Chr.
(4) *Scolia oryctophaga* Coq.
(5) *Scolia ruficeps* Smith.

Scolia ruficornis, a parasite of the East African species of *Oryctes* was recently added to this list by Simmonds (1949). *Scolia patricialis* Burm., var. *plebeja* Girb., is reported to parasitise *Oryctes* larvae in Malaya by Bryan, Jr. (1949).

In India, so far, no *Scoliid* parasites have been found to parasitise this pest in the important coconut growing areas.

Predators. A number of predators have been observed in the breeding sites of *Oryctes*, but most of these are general predators on other insects also. However, a combined effect of these predators keeps the population of *Oryctes rhinoceros* under check to some extent. The more important of these are the following: —

(1) *Insects.* There are several known predators of *Oryctes* and probably many more are not yet recorded. The Carabid, *Mecodema spinifer* and the Histerid, *Pachylister chinensis* Quensel, are predacious on *Oryctes* larvae in Samoa. Similarly certain species of the genus *Leionota* (Histeridae) have also been reported to prey upon *Oryctes* larvae in Fiji.

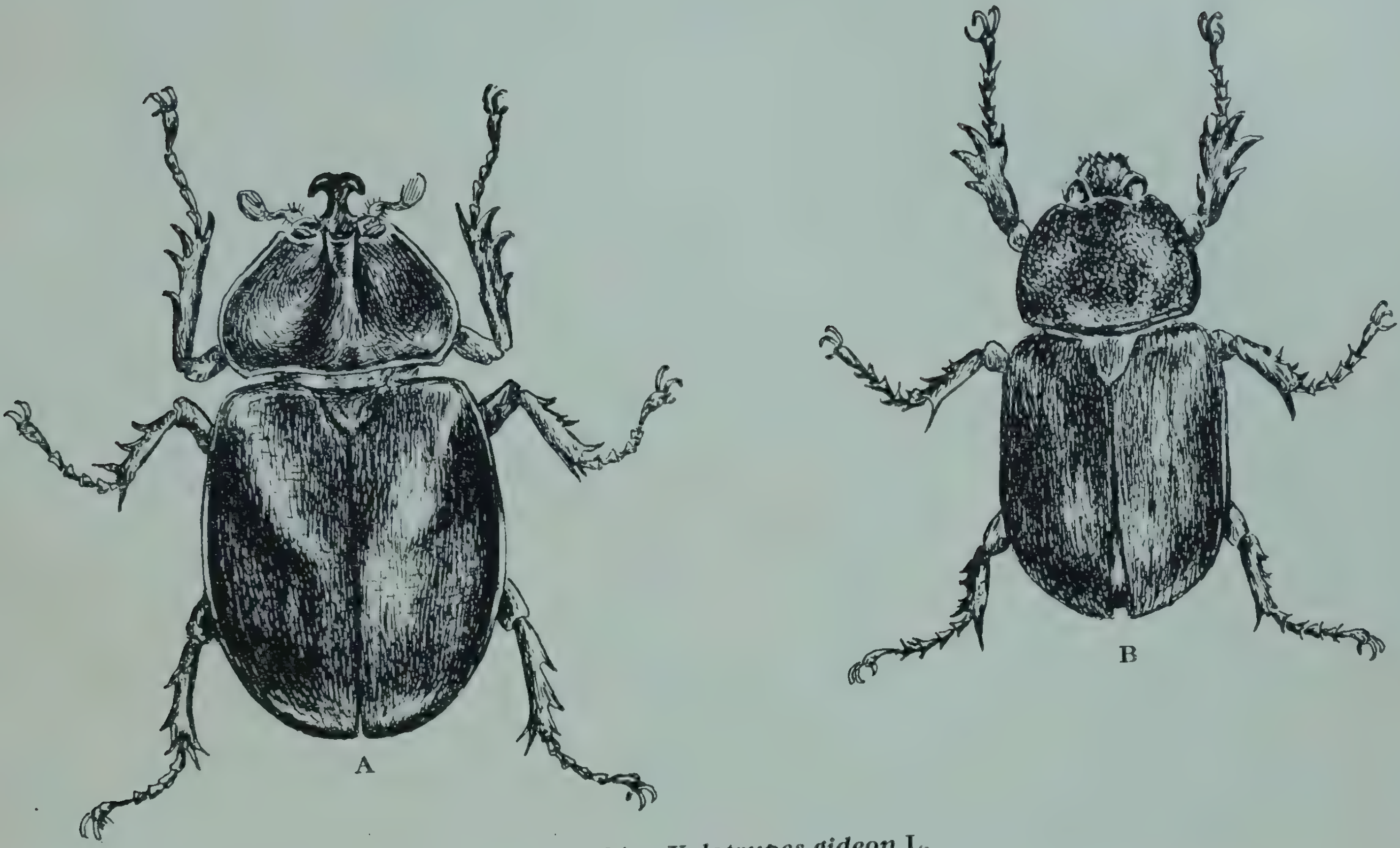


Fig. 94. *Xylotrupes gideon* L.
A. Male, B. Female

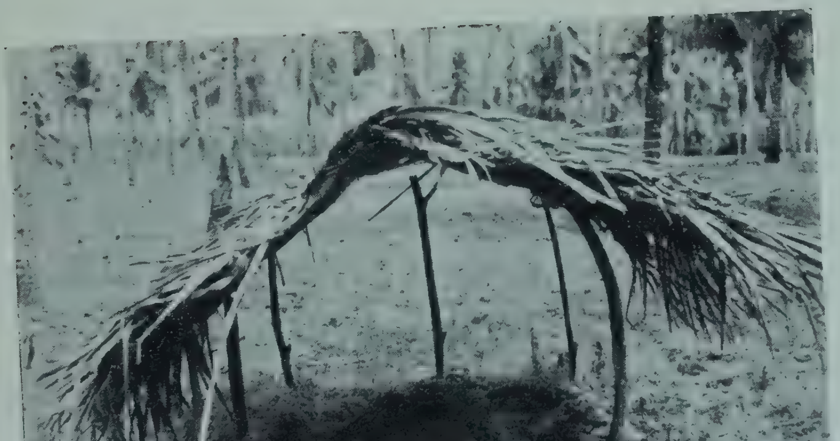


Fig. 95. Beetle trap

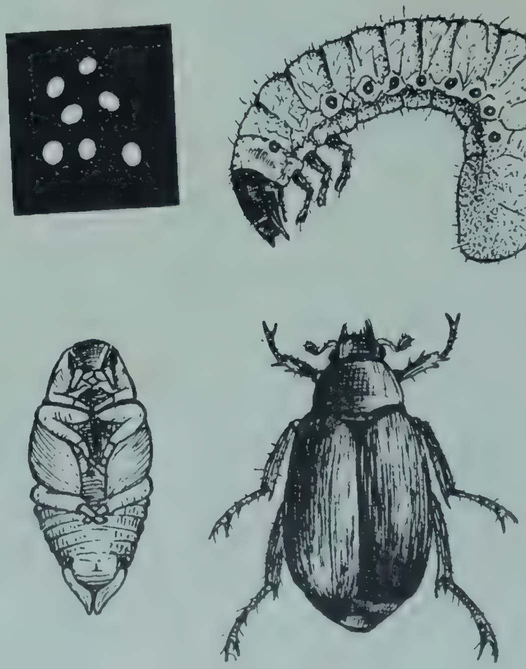


Fig. 96.
Leucopholis coneophora —
different stages

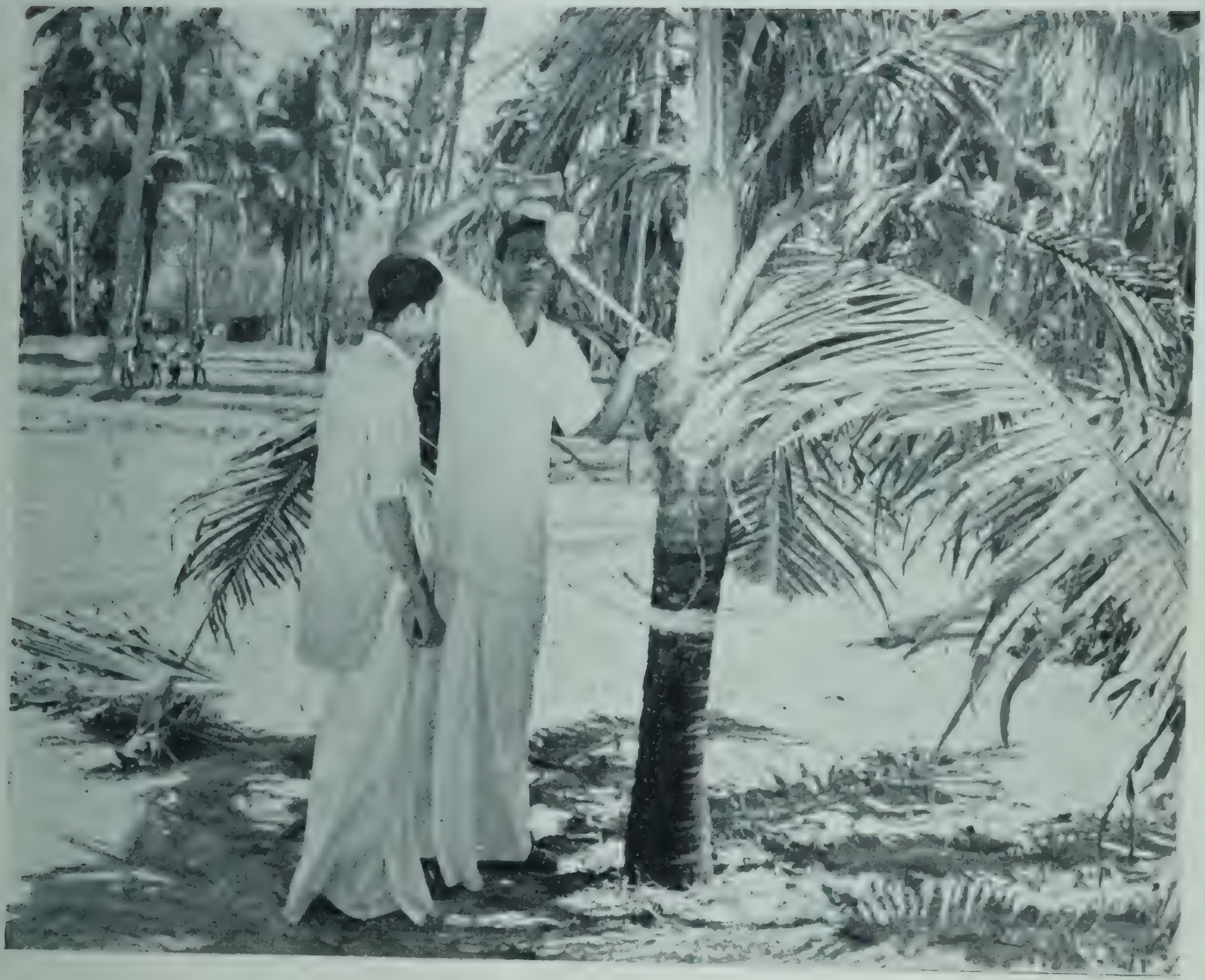


Fig. 97. Injecting against red palm weevil

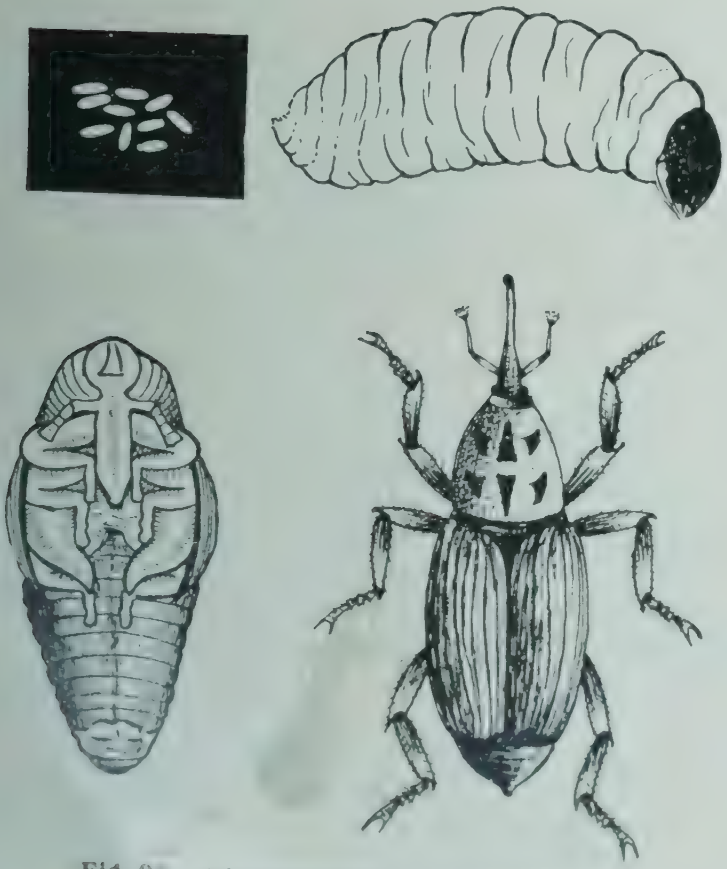


Fig. 98. *Rhynchophorus ferrugineus* — different stages

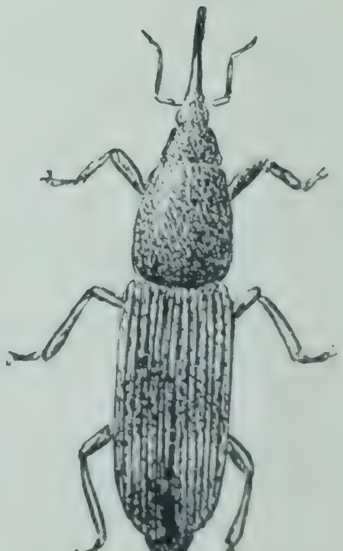


Fig. 99. *Diocalandra stigmaticollis*

In India, *Carabid*, *Histerid* and *Elaterid* beetles and their larvae have been met with in the breeding places of *O. rhinoceros* but none of these has ever been found to exert any appreciable effect on the population of the pest (Nirula, 1955).

(2) *Frogs and toads.* Frogs and toads are quite often seen in the breeding places of *Oryctes rhinoceros.* They feed on the young larvae of the beetle.

(3) *Birds.* Picking of the grubs by crows, wood peckers, etc. is a common sight, whenever any manure heap having such grubs is raked up. Raking up of the breeding materials has been suggested as a means of control by some of the workers.

(4) *Rats and squirrels.* Rats and squirrels also take a good toll of the *Oryctes* larvae.

(5) *Pigs.* Pigs destroy a large percentage of *Oryctes* eggs, larvae and adults present in the refuse heaps.

(6) *Domestic animals.* Of the domestic animals, fowls and ducks readily feed on accessible *Oryctes* larvae.

Entomogenous fungi

The entomogenous fungus *Metarrhizium anisopliae* (Metch) Sor. was first reported attacking *Oryctes rhinoceros* in Samoa by Friederichs (1913). He suggested its use in the breeding traps for the control of the rhinoceros beetle. Bryce (1915) working on this fungus in Ceylon did not advocate its use as an agent for the control of the rhinoceros beetle. Hopkins (1927) reviewed the work of Friederichs in Samoa, and felt that the Samoan strain of the fungus was particularly virulent. In 1953, investigations on this fungus were started at the Central Coconut Research Station, Kayangulam, and some interesting observations were recorded (Nirula *et al.*, 1955). The cultural characteristics, etc. of the fungus were studied and variations in spore measurements in different strains and differences in pathogenicity were noticed (Radha *et al.*, 1956). The possibility of using this fungus for the biological control of the rhinoceros beetle is under investigation.

Economic Importance

It is difficult to assess the financial loss to the coconut industry caused by this beetle. It has been observed that at least one spathe in each tree is damaged by the beetle every year. A healthy coconut palm puts out an average of 10 spathes annually and therefore loss of about ten per cent in the yield of nuts may be expected.

There is not much evidence to show that the beetle directly causes the death of the grown up palms in South India. But stray cases have been known, where seedlings and young palms have been killed by the repeated attack of the beetle. It also paves the way for subsequent infections by pathogens. Recent reports of the damage caused by this beetle in Assam and the Andaman Islands are very alarming. The beetle presents a colossal problem to the coconut industry in those areas.

Outside India the beetle causes havoc in the South Pacific Islands. The mortality of palms has been up to 50 per cent in some of the islands like Palau due to the direct attack of the rhinoceros beetle. Reports of similar damage from other islands in South Pacific are also quite frequently received.

Control

Mechanical. The control of the rhinoceros beetle by mechanical methods has received considerable attention in India and other coconut growing countries of the world. These mainly consisted in tackling the breeding places of the beetle and destroying its earlier stages of development such as eggs, grubs and pupae, and the direct method of examining the palms periodically and extracting out the beetle by means of a hooked pointed rod.

There appears to be close correlation between the abundance of available larval breeding environments and damage by adult beetles to palms. In order to properly control *Oryctes*, all such breeding places must be rendered innocuous or the grubs collected from them regularly. Leefmans (1920) and Corbett (1932) suggested the burning or deep burying of the breeding materials, but Nirula (1955) advocated suitably treating the materials with insecticides like BHC.

The removal of beetles from the crown of palms is carried out by means of a beetle hook. This is a metal rod about half a metre in length and half a centimetre in thickness, with a sharp hook at one end and a loop at the other. The pointed end is inserted to extract beetles from holes. This method is advocated mostly for the extraction of the beetles which burrow deep into the crowns of the young palms. After extraction of the beetle, the hole should be filled with sand or sand mixed with 5 per cent BHC dust.

Biological

Consideration has been given to the control of *Oryctes rhinoceros* by Scoliid wasps, *Campsomeris luctuosa* Smith., *Scolia procer* Ill., *Scolia azurea* Chr., *Scolia oryctophaga* Coq., *Scolia ruficeps* F., and *Scolia patricialis* Burm. These have been described as parasites on the grubs of the beetle. There are some reports of parasitism of *Oryctes* grubs by Dipterous flies (Venkitasubban, 1938 and Venkataraman *et al.*, 1954). There are several known predators of *Oryctes* and most of these belong to the families *Carabidae*, *Elateridae* and *Histeridae*. However, no insect parasite or predator has been found which satisfactorily controls *Oryctes rhinoceros*. The recent introduction of *Scolia ruficornis* F., into Western Samoa for the biological control of *Oryctes* is being watched with great interest.

Chemical

The destruction of the younger stages of *Oryctes rhinoceros* in the breeding places has long been considered as an efficient method of controlling this serious pest, but the procedure suggested by the earlier workers consisted in mechanical collection and quite often complete destruction of the entire breeding materials. Various insecticides were tried for the control of the *Oryctes* larvae in their breeding places. These chemicals included DDT, DDD, toxaphene, BHC, chlordane, calcium arsenate, lead arsenate, paris green and sodium arsenite. Of these, BHC at a strength of 0·01 per cent was found quite satisfactory for killing the larvae of the beetle. Sodium arsenite and other arsenic salts were also toxic to *Oryctes* larvae, but due to their being highly poisonous to cattle, poultry and human beings, these have to be used with caution.

BHC was extensively tried in the different types of breeding materials and under varying environmental conditions and its effect was found to persist for a period of six months.

Phytotoxicity of BHC to roots of coconut palms and other inter-cultivated crops was studied and it was found that at the recommended dosage, BHC did not adversely affect the plants.

In the case of compost heaps, it was found that spraying of BHC gave better control than dusting. Compost heaps could be sprayed up to a depth of two feet.

A field experiment conducted at the Central Coconut Research Station, Kayangulam, showed that if the breeding inside a block and outside in a belt of 200 yards was controlled, the incidence of attack in the block could be kept under check. The experiment was started in August 1951, when the incidence of fresh attack was 40 per cent ; it fell to below five per cent within a period of twelve months.

When favourite breeding grounds have been largely eliminated, trapping proves an effective method of control, but it will be of little or no avail if decaying materials in coconut groves, neighbouring fields, forests or villages have not been properly disposed off or treated with BHC. The traps consist of attractive breeding materials treated with 0·1 per cent BHC, heaped up on the ground and covered by coconut plaited leaves (Fig. **95**). The beetles which visit these for resting, mating and oviposition, get contaminated by the insecticides and are killed.

During dry weather, filling of the axils of the central leaves in the crowns with a mixture of sand and 5 per cent BHC dust in equal proportions gives some protection to the palms from the beetle attack.

Several repellents like coal tar, " Mason mixture ", and tar oil wash and attractants like fermenting rice water, toddy, rotting castor cake, etc., were tried but without success (Nirula, 1955).

Oryctes sp.

The genus *Oryctes* contains about forty-two species, twenty-five of which attack palms and out of these fifteen are pests of the coconut palm (Gressitt, 1953). The more serious pests of coconut in East Africa are *Oryctes monoceros* Ol., *O. gigas* Cast., *O. boas* Fa., and *O. owariensis* P.de. B., *O. tarandus* Ol., and *O. chevrolati* Guerin are pests of coconut in Mauritius and Reunion and *O. latecavatus* Fairm., *O. pyrrhus* Burm., *O. ranavalo* Coq., and *O. simiar* Coq., in Madagascar. *O. trituberculatus* Lamb., causes damage to coconut palms in Malaya. *O. australis* is a pest of young coconut palms in Papua.

The information concerning these beetles is limited, but according to available reports their habits are similar to those of *Oryctes rhinoceros.*

Strategus sp.

These are not the true ' Rhinoceros ' beetles but are known by that name in the West Indies. They have been occasionally observed as pests on coconut palms in Puerto Rico and some other islands of the West Indies, and are sometimes called the " coconut rhinoceros beetles ".

Xylotrupes gideon *L.*

This beetle has been occasionally noted on coconut palms in association with the rhinoceros beetle, *Oryctes rhinoceros*. It feeds on the under surface of the leaf petioles and as a result the apical portion of the leaf breaks down. This leaf-break is an indication of the presence of this beetle. In addition to feeding on the leaf petioles of the palm, it is often seen gnawing the branches of the inflorescence. According to Nirula it is capable of causing more severe damage than the rhinoceros beetle.

The male and female (Fig. *94*) of *Xylotrupes gideon* L., are strikingly different in appearance. The male is about 45 mm in length and is chestnut coloured. The head is armed with a horn projecting forward and terminating in two recurved points. The pronotum is drawn out into a cone directed forwards and produced at the apex into a gently curved bifid horn. The female is generally reddish-brown in colour and smaller than the male, and has no projections from the head or the pronotum. The larvae of this beetle are found in the decaying organic matter and they resemble very much the larvae of *O. rhinoceros* excepting the structure of the spiracles.

Duration of its life cycle is not known, but according to Corbett (1932), it probably lasts from three to four months in Malaya.

Control measures recommended for *O. rhinoceros* are applicable for this beetle also.

LEUCOPHOLIS CONEOPHORA *Burm.*

The cockchafer, *Leucopholis coneophora* Burm., is another serious pest of coconut palms in certain areas of Kerala, India. The larvae of the pest feed on the roots of the coconut palms and cause untold havoc. The worst damage to the palms is done just after the pre-monsoon showers in March, April and May, when the grown up larvae move up in large numbers from the depths of the soil to the surface and attack the roots near the bole of the palms. The leaves of the attacked palms turn pale yellow, and there is reduction in the formation of nuts. During periods of heavy attack, the immature nuts fall off from the stalks, and the palms appear quite barren. In young coconut palms, the growth is stunted and the flowering delayed. In the affected areas, it is a common sight to find palm after palm without any nuts. Besides coconut palms, the pest attacks the inter-cultivated crops like tapioca, sweet potato, colocasia, plantains, etc.

The pest was first recorded by Nirula *et al.* (1952), who gave a brief account of its distribution, description and the nature of damage. Further information on the pest was added by Nirula (1957), who in addition to describing the life history, suggested some control measures.

Distribution and habit

As a coconut pest *Leucopholis coneophora* Burm., is found only in India according to Nirula (1957). In India it has been recorded from Mavelikara and Tiruvella taluks of Quilon district, certain areas in Trichur district and from Quilandy, Nadapuram Road and Mahe in North Malabar. It is quite likely that the pest may also be present in the adjoining areas.

The areas in which the pest is endemic, have a number of features in common. There is relatively high rainfall, the soil is mostly sandy, invariably light and slightly acidic. The infested areas comprise mostly coconut growing lands which are extensively inter-cultivated with tapioca and other root crops. Wherever outbreaks occur, some or all these features are found to characterise the infested areas.

Within the infested districts the distribution of *Leucopholis* is markedly local. It is quite usual to find one coconut garden heavily infested and the adjoining field free of beetles and larvae. Even within a garden the distribution is irregular.

Description of the pest

Leucopholis coneophora Burm., belongs to the family Melolonthidae. It was described as a new species by Burmeigter. The genus *Leucopholis* is confined to the eastern tropics and sub-tropics and some of its species are serious pests in Java, Ceylon and the Philippines.

Adult

The adult beetles are chestnut-coloured, about 30 mm in length and 14 mm in width. The elytra are longitudinally striated finely coriaceously sculptured and do not cover the abdomen completely. Legs are hairy and long. Sexual dimorphism is not marked, but according to Nirula the sexes can be determined by the following characters :—

(*a*) In general males are smaller than the females.
(*b*) In females the abdomen is broader posteriorly, while in the male it is uniformly narrower both anteriorly and posteriorly.
(*c*) The tibial spurs of the hind legs in females are broader towards the apex, while those of the males are more slender and pointed.

Egg

The egg is oval in shape and creamy-white in colour when freshly laid. It is translucent and its surface is perfectly smooth. It is about 4·5 mm long and 3·5 mm wide. The eggs absorb moisture, increase in size and change shape and colour during development. Before hatching, their colour is dirty-white and they are about 5·5 mm in length and 4 mm in width.

Larva

The larvae are white with brown heads and fleshy bodies. The mandibles and maxillae are strongly built and well developed. The head is prominent, downwardly inclined and strongly chitinized. The three thoracic segments are short and legs close together. The legs are well developed and hairy, but rarely used for locomotion. The first pair of the legs is the shortest and the last pair the longest. The dorsal surface of the abdominal segments is covered with short spine-like hairs and being brown in colour, they give a rusty appearance to the humped part of the back and even in the field this character makes the larvae easily distinguishable. The caudal segments of the abdomen are very large and shiny with the dark body contents showing through the skin. The ventral surface of the last abdominal segment bears two longitudinal rows of short spinules and this character easily differentiates it from the larvae of *Oryctes rhinoceros* and other Scarabaeid beetles. The grubs when crawling, generally lie on their back and work themselves forward by a peculiar movement of the body ridges. Grubs when fully grown measure about 60 mm in length and 12 mm in width.

Pupa

Pupae resemble the typical fleshy Scarabaeid pupae and are extremely susceptible to handling. Before pupating, the grubs form oval pupal cells in the soil where the pupae can develop safely. The pupae are uniformly brown in colour and slightly convex dorsally. The legs and wing cases are distinctly folded on the ventral surface. The pupa varies in size from 30 mm to 50 mm in length and 15 mm to 25 mm in width (Fig. 96).

Life history

The female beetles lay their eggs in the soil at a depth of three to six inches, very close to the roots of the grasses or in the vicinity of decaying organic matter, so that the resulting larvae have at their disposal plenty of suitable food material. Soil moisture is an important factor for the development of eggs.

Before hatching, the brownish mouth parts of the tiny larva become visible through the translucent egg shell. The freshly emerged larvae rest for a few hours and then start moving about in search of food. Larval development depends upon a number of environmental factors, the more important of which are temperature, humidity and texture of the soil. The larvae keep on adjusting themselves to the change of environment. During night and early morning the larvae are quite close to the soil surface but as it starts getting hot, they migrate into deeper layers. The young larva feeds on organic matter and grass roots, but during its second instar when it has attained a length of about 20 mm, it starts feeding on the roots of the coconut palm and inter-cultivated crops. The larva feeds continuously during the favourable conditions and grows rapidly in size. It ingests the soft portions of the roots, but in reaching these parts, it has to bite through the hard hypodermis. The larvae are able to stand water-logged conditions of soil, but during such periods, they move very close to the surface of the soil.

When the larva is fully mature, it stops feeding and moves about in search of a suitable site to form its cocoon which is generally found deep in the soil. The pupation takes place inside an earthen cocoon. A certain amount of moisture is very essential for the proper development of pupae and if the soil around becomes very dry, the development is delayed and in cases of extreme drought, pupae may die.

The adult comes out by splitting open the pupal skin and rests for some time in the cocoon before coming out. The emergence from the soil takes place after about a fortnight of the first showers of the south-west monsoon on the West Coast, and the characteristic feature of the emergence is the abruptness with which it begins. For a few days, stray beetles may be seen; then quite suddenly there is a mass emergence, which invariably begins after sunset and is completed within half an hour. For some days before the mass emergence, fully formed adults may be found lying quiescent in the soil. Another striking feature about the mass emergence noticed was, that it occurred almost simultaneously at places situated about eight to ten miles from each other. The beetles remain active for about two hours of their emergence and then again burrow into the soil. The beetles come out of the soil in the early hours of the morning also and remain active for about an hour. They are not attracted to light, but sometimes during the peak emergence period, some stray individuals may come towards the light. Pairing takes place during the period of activity outside the soil, and oviposition starts after about five days. Under laboratory conditions oviposition continued for about a fortnight, but it is likely to be much longer in the field.

Nirula (1956) is of the view that *Leucopholis coneophora* Burm., has an annual life cycle. The adults appear in early or middle June, and remain active for about eight weeks. The eggs laid during this period of activity in June and July hatch out in about twenty days. The larvae continue to feed till the end of April or early May of the following year, when feeding ceases and after a short prepupal period the larvae finally moult into pupae. The pupal stage lasts for about thirty days, and before coming out, the adults remain in the soil for some time, the final emergence taking place during June.

Control

Predators

Birds are the most important predators of the larvae of this pest, and are extremely active when the soil is ploughed up in the infested areas from March to May. The common crow is the most useful bird in this respect. The striped squirrels were also observed turning up the loose soil in search of these grubs. Dogs, cats and bats are fond of eating the adult beetles and during the periods of peak emergence these collect in the infested areas and destroy a large number of beetles.

No parasite on any stage of the development of the pest has been recorded so far.

Cultural

Tilling and deep ploughing of the soil at the time of abundance of the pest, have been suggested as measures of control. Not only are the conditions less stable in arable land, but also the cultivation may damage the organisms, expose them to predators or the risk of desiccation. However this is only a palliative method and not enough to secure full control.

Chemical

The application of BHC and DDT to the soil was tried and it was found that 56 lb of 10 per cent BHC dust applied per acre once a year, gave control of the pest. However, later work revealed that 5 per cent chlordane dust applied at 28 lb per acre also gave satisfactory results.

The insecticide is applied to the soil by a hand duster and the soil is either tilled or ploughed up to six inches deep.

RHYNCHOPHORUS FERRUGINEUS *F.*

The palm weevil, *Rhynchophorus ferrugineus* F. is the most destructive pest of young coconut palms. Unlike the rhinoceros beetle, the adult weevil is incapable of causing any direct damage to the tree; on the other hand, the early stages of the weevil are passed on the palm and the damage caused to the tree by the weevil larvae is often fatal. It is estimated that about 0·5 per cent of the palms are attacked by this pest every year in Travancore-Cochin alone. In India, information on this insect was first published in 1891 in the *Indian Museum Notes*. This was supplemented by Lefroy (1906), who described it as a local sporadic major pest of coconut and other palms throughout India. Later on Ghosh (1911), Fletcher (1914, 1917 and 1919), Stebbing (1903), Nirula *et al.* (1953) and Nirula (1956) contributed a good deal of information about the biology and control of this pest.

In Ceylon, Green (1906) mentioned it as a serious pest of coconut palms and Henry (1911), Brand (1917) and Hutson (1933) published the biology of the pest and suggested some preventive control measures. Leefmans (1920) who published the first original investigation on the pest in Indonesia reviewed the work done in other countries, gave a complete description of the pest and suggested some control measures. In the Philippines, Banks (1906), Copeland (1931), and Viado and Bigornia (1949) worked on this insect.

In Malaya, the red-stripe weevil *Rhynchophorus schach* Oliv., which was referred to as *R. ferrugineus* variety *schach*, has recently been raised to the status of a separate species. Corbett (1932) worked out the life-history of this weevil and suggested some control measures.

Another closely allied species of the weevil, *R. palmarum*, is an equally dangerous pest of coconut palms in the western tropics.

Host Plants

It is commonly found on the coconut palm, the date palm, *Phoenix dactylifera* the sago palm, *Metroxylon sagu*, and the toddy palm, *Phoenix sylvestris*. The palmyra palm *Borassus flabellifer*, the oil palm, *Elaeis guineensis*, the talipot palm, *Corypha umbraculifera*, the sugar palm, *Arenga saccharifera*, the serdang palm, *Livistona chinensis*, the nibong palm, *Oncosperma tigillaria*, the royal palm, *Oreodoxa regia* and some ornamental palms also have been reported to be attacked by the weevil.

In South Travancore it was reported breeding in the aloe, *Agave americana*. Leefmans (1920) observed it breeding in the rubbish left behind after sago manufacture. Recently Salgado (1952) has reported the breeding of the weevil in the decaying crowns of felled coconut palms in Ceylon.

Distribution

Rhynchophorus ferrugineus is a serious pest of coconut palms in India and Ceylon. Ghosh (1923) described it as a pest of coconut and other palms in Burma. Leefmans has reported its presence throughout Indonesia. In the Philippines, this species is a very serious pest of coconut palms. According to Copeland (1931), the known distribution of the pest was from India to the Philippines, and he felt it likely to reach upto New Guinea.

Buxton (1920) found the weevil causing serious damage to date palms in Mesopotamia (Iraq). It is quite likely that the weevil is present in other middle east countries where date palms are grown in abundance.

Lefroy (1906) described it as a local sporadic major pest of coconut and other palms throughout India.

Symptomatology

It is very difficult to detect the presence of the pest infestation in the earlier stages of attack. The grub begins its life inside the palm, and normally never comes outside. Therefore neither the grub nor the damage caused by it can be readily seen. Sometimes, a few small holes occur in the crown or the soft stem from which pieces of chewed fibres protrude and a brownish viscous liquid oozes out. In many cases the drying up of the young heart leaves or splitting of the petioles near the area of attack can be observed. But most often the attack by the weevil is noticed only when the tree has been fatally infested and is beyond repair.

Description of the Pest

Egg

The eggs of the weevil are creamy-white in colour, long, oval in shape and slightly broader at one end. They are translucent, perfectly smooth and shining. The average size of an egg is 2·62 mm long and 1·12 mm wide. The eggs slightly increase in size before hatching and the brown mouth-parts at the narrow end of the egg can be distinctly seen through the shell.

Larva

The full grown grub is a conical shaped larva, bulged in the middle, and pointed towards both ends. The larva is stout, fleshy and apodal. The body is composed of thirteen segments. The head is brown in colour and pointed downwards. Mouth parts are well developed and strongly chitinised, which enable the grubs to burrow into the hard woody portions of the palms. The prothorax is very large and bears two transverse oblong patches, which are darker in colour than the rest of the body. All the other segments are soft, fleshy, non-chitinised and light brown. The skin is wrinkled over the body. The average length of the larva, when fully grown is 50 mm, and the mean width in the middle is 20 mm. The freshly hatched young larva is yellowish-white in colour, with pale brown mouth parts.

Cocoon

When about to pupate, the larva constructs a cocoon of fibre. The inside fibres are more closely matted together than those outside, which are arranged spirally. The interior of the cocoon is smooth and is plastered with a dark coloured secretion. The cocoon is oval in shape varying in length from 50 mm to 95 mm and in width from 25 mm to 40 mm.

Pupa

The pupa is at first cream coloured but later turns brown. Its surface is shiny, but greatly furrowed and reticulated. The head is bent ventrally, the rostrum reaching the tibia of the first pair of legs. The antennae and eyes are quite prominent. The sheaths of the appendages are closely apposed to the body. The average length of the pupa is 35 mm and the width is 15 mm.

Weevil

The adult insect is a ferrugineus-brown, cylindrical weevil with a long prominent curved snout. It varies considerably in size and is about 35 mm in length and 12 mm in width. The head and rostrum comprise about one-third of the total length. The mouth parts are elongated in the form of a slender snout or rostrum, which bears a small pair of biting jaws at the apical end and a pair of antennae near the base. In the male, the dorsal apical half of the snout is covered with a patch of short brownish hairs ; the snout of the female is bare, more slender, curved and a little longer than that of the male (Fig. *98*).

Life history

The female weevil starts egg laying generally from the fifth day of its emergence, and the eggs are laid singly in the softer portions of the palms. Sometimes the eggs are laid loose, when there is enough of moist decaying matter in the trunks of the palms. The incubation period of the eggs varies from two to five days depending on the prevailing weather conditions.

When the egg hatches, the larva begins feeding towards the interior of the palm stems. In tunneling the palm, the larvae do not ingest the fibrous strands, but take into the system only the soft succulent material, the fibrous material being gradually worked underneath the body and finally blocking the tunnels. The larvae may be found in any part of the palm, viz., the bole, stem or the crown in case of young plants up to five years old. But as the palms advance in age, the grubs are generally confined to the portions of the stem close to the growing point. In palms above fifteen years, the larvae are generally found in the stem two or three feet below the crown, in the crown and in the bases of leaf petioles. The larval period ranges from 36 to 78 days and is on an average 55 days (Nirula *et al.*, 1953).

The fully developed grubs, construct their cocoons by winding around themselves a number of tough fibrous threads to form a stout, compact, elongate-oval cocoon. After completion of the cocoon, the larva shrinks and subsequently assumes an inactive form known as the pre-pupal stage. This stage lasts for about three days and the grub moults for the last time and changes into a pupa. The pupal period varies from 12 to 20 days.

The weevils after emergence from the pupal cases, remain inside the cocoon, and this period ranges from 4 to 17 days with an average of 8 days. According to Hutson (1933), the weevils become sexually mature during this period of inactivity.

The weevils remain active during day and night, with short intervals of rest, the resting periods being longer at night. The flight and crawling of the weevils are generally restricted to day time, and such activity is at its maximum from sunrise to 9 a.m. and from 5 p.m. to sunset. According to Leefmans (1920) weevils are capable of long flights and can find out their host plants in widely separated areas.

Copeland believed that the weevils did not feed, but visited the palms for oviposition only. It was recorded that the weevils definitely feed and cannot live without food for more than a week. Mating takes place at any time of the day and the males and females mate many a time during their lifetime. The female generally starts oviposition from the day succeeding pairing, but sometimes this period may be extended upto one week.

The weevils, when ovipositing confine themselves to the softer portions of the palms. Considerable divergence of opinion exists as to the places where eggs are laid. Copeland, Hutson (1933), Ayyar (1940) and some others believed that the weevil could lay its eggs only in those palms where the soft tissues have been exposed in some way. It was recorded that in the young palms upto seven years of age, the females could infest them by laying the eggs in the softer tissues of the crown. However in grown-up palms, infestation cannot be effected, unless the softer tissues are exposed. This may happen by an injury caused by lightning, fire, accidental cutting of the stem and the attack of the rhinoceros beetle. The grubs may enter through the cut petioles, and experiments have proved that the larvae hatching out of the eggs laid into the cut ends of two-feet-long petioles, entered the crown in about twenty days. Trees where the central shoot has been affected by the attack of the ' leaf disease ' or ' bud-rot ' also invite the weevils for oviposition. Recently in Kuttanad in Travancore where the leaf rot is spreading, a large percentage of palms has been found to be infested by this pest.

Oviposition continues for about 45 days and during this period the weevil lays on an average 204 eggs. The maximum number of eggs laid by a single female in captivity was 355 in 42 days and the minimum was 76 in 26 days. There is always a short post-oviposition period of about ten days, before the weevil dies.

The weevils of both sexes live for approximately two to three months. In captivity, the maximum duration of adult life in cages was 76 days for the female and 113 days for the male.

The complete life cycle from the laying of the egg to the emergence of adult takes on an average 82 days on the West Coast of India. With such a short life cycle and prolific breeding habits, the pest can multiply in geometrical proportions. A single pair can theoretically give rise to more than fifty-three million weevils in four generations, in the absence of controlling factors.

Parasites and Predators

Friederichs (1913) recorded *Scolia erratica* Smith as a parasite of the larvae of *Rhynchophorus ferrugineus* F., in Singapore. But Copeland in the Philippines, Leefmans in Indonesia and Hutson (1933) in Ceylon have not found any Scoliid parasitising this pest.

Nirula recorded a species of mites belonging to the family Pyemotidae as an external parasite on the pupae and adults of the weevil. This mite feeds by penetrating the integument of its victim with its mouth parts and sucking out the body fluid. The mites are unable to pierce through the pupal cocoons, and are generally carried inside the cocoons, by the pupating larvae.

Control

The methods suggested for the control of this pest, by earlier workers were only preventive and mechanical. Copeland, Leefmans, Hutson and Ayyar prescribed that all scars, wounds and exposure of soft parts of palm should be avoided as a prophylactic measure of control. In the case of attacked palms they suggested the scooping out of the grubs mechanically and dressing the wounds with repellents like tar, lime, etc. All these workers were of the opinion that a tree, in which the grubs had gained deep entry and were sufficiently protected from external disturbances was to be cut and burnt so that the neighbouring trees may be protected.

Nirula *et al.* (1953) tried a number of insecticides like DDT, BHC, toxaphene, DDD, lead arsenate, paris green, copper sulphate, pyrocon-E. (a mixture of one part of pyrethrins and 10 parts of piperonyl butoxide) and Killoptera (a mixture of ethylene dichloride and carbon tetrachloride in the proportion of 3 : 1 by volume), against this pest both in the laboratory and field on a large scale. It was found that 1 per cent pyrocon-E. in water when injected into infested trees gave the best results. Young palms, six or seven years old, required about 1,000 cc of 1 per cent pyrocon-E. and full grown palms from 1,000 cc to 1,500 cc. The exact quantity required depended on the severity of attack. The insecticide was poured through a funnel (Fig. 97), which was fixed in a hole a little above the infested portions. After the insecticide had percolated into the palm, the hole was closed. It was found that if the growing point of the palm had not been destroyed, the trees recovered.

As a prophylactic measure of control, the leaf-axils of young palms should be filled with sand and five per cent BHC, or sand and five per cent chlordane in equal proportions. For a young palm, six to seven years of age, one pound of the mixture would be sufficient and it should be well distributed in all the leaf-axils. Before laying eggs the weevils rest in the leaf-axils and contact with the insecticide proves fatal to them.

RHYNCHOPHORUS SCHACH *Oliv.*

This weevil is a pest of coconut palms in Malaya, the Philippines, Celebes, Java, Sumatra and Borneo. It can be differentiated from *Rhynchophorus ferrugineus* F., by its prevailing black colour and the presence of a red stripe on the pro-thorax. It was earlier referred to as *R. ferrugineus* var. *schach.*, but recently has been elevated to specific rank, and known as *R. schach* Oliv.

In its habits and life history it very much resembles *R. ferrugineus*. Corbett (1932) believed that this weevil constituted the most dangerous threat to coconut palms in Malaya.

The measures suggested for the control of *Rhynchophorus ferrugineus* F., may also be successful for the control of this weevil.

RHYNCHOPHORUS PALMARUM *L.*

The palm weevil *Rhynchophorus palmarum*, is a serious pest of coconut palms in the American tropics. The adults of this weevil are black in colour and velvety when freshly hatched, but in a short time this pubescence disappears and the weevils appear shining black. Young coconut palms from two to five years of age are the ones mostly attacked. When once established in a tree, the larvae soon reduce all the soft tissues to a mass of coarse fibres leaving the stem quite hollow. In addition to causing direct injury, these weevils are believed to spread the red ring disease of coconut palms, which is caused by the nematode *Aphelenchus cocophilus* Cobb.

Urich (1911) has suggested employing of traps consisting of the fermenting cabbage portion of the palm, for catching the adult weevils.

RHINA BARBIROSTRIS *F.*

This is commonly known as ' Bearded weevil ' and is very common in the western tropics along with *Rhynchophorus palmarum*. The damage is done by the larvae of the weevil. Unlike *R. palmarum*, full grown trees are favoured by the female of this for oviposition and the larvae bore regular galleries like longicorn beetle larvae, in the hardest part of the stem. The attack of the larvae causes a mechanical weakening of the stem which breaks off in strong winds.

DIOCALANDRA STIGMATICOLLIS *Gyll.*

The small brownish-black weevil, *Diocalandra stigmaticollis* Gyll. is quite often seen in the decaying portions of the coconut palm. It frequently inhabits the petioles, but is present in any part of the palm, where decay has commenced. Fletcher (1919) considered it as a bad pest of coconut palms in Ratnagiri district (Bombay). Joseph (1949) recorded this pest on some badly affected coconut palms in Quilon (India). Recently these weevils have been found in very large numbers on coconut palms in Kumarakom, Kottayam (India), associated with the stem bleeding disease.

The weevil (Fig. *99*) is dark brown in colour, with a faint black patch on the pro-thoracic region. It has a long pointed snout with a gentle inward curve. It is about 6 mm in length and 1·5 mm in width. The larva is dull white in colour, about 8 mm in length, having a wrinkled and curved body without legs.

PROMECOTHECA REICHEI *Baly*

Promecotheca reichei Baly is a Hispid beetle, the larvae of which mine in the leaflets of the coconut fronds in Fiji, Samoa and Tonga. The adults feed on the leaves. It is a very serious pest and during severe infestations, the combined activity of the larvae and the adults results in a reduction of upto 75 per cent of the functional leaf surface.

In normal circumstances the pest occurs in overlapping generations, with the result that at any time all the stages of the pest are present but a satisfactory equilibrium is maintained by the inter-relationship of indigenous primary and secondary parasites. According to Evans (1952), this equilibrium was upset in parts of Fiji by the Tarsonemid mite, *Pediculoides ventricosus* Newp., which was first recorded in the islands in 1921. The mite attacks the larvae, pupae and freshly emerged adults of *P. reichei* and reduces it to very small proportions, with the result that the pest occurs in a single stage at a time and the generations do not overlap and in this condition it is not controlled by indigenous parasites and assumes the status of a pest.

Taylor (1937) made a thorough search for parasites and introduced the Entedontid *Pleurotropis parvulus* Ferr., from Java. This Entedontid had a rapid rate of multiplication and attacked its host not only in the larval stage of development but also in the pupal stage. This parasite soon established in Fiji and the pest was brought under control.

PROMECOTHECA sp.

Promecotheca cumingi Baly is a pest of coconuts in Malaya. The adults feed on the leaves and the larvae live in coconut leaves, and give them a scorched appearance.

Promecotheca opacicollis Gestro. is an important pest of coconuts in Solomon islands. The larvae inhabit coconut leaves and the adults feed on the leaf surface. The pest causes heavy damage in districts of low rainfall.

Promecotheca papuana Csiki is a serious pest of coconut palms in New Guinea. The grubs feed in between the two layers of the leaf causing large areas of dead tissues and the adult beetles feed on the surface tissue. With a heavy infestation, the fronds appear brown, as if scorched by fire, especially when viewed from a distance. Froggatt and O'Connor (1954) have given a detailed account of this pest and suggested some control measures, which include spraying the attacked palms with lead arsenate and nicotine sulphate.

PLESISPA REICHEI *Chap.*

This Hispid is an important pest of coconuts in Malaya and it is known as ' Two coloured coconut leaf beetle '. The adult beetles are flat, varying in length from about 6 mm to 8 mm.

Plesispa reichei Chap. both in the larval and beetle stages, feeds upon the upper and lower surfaces and confines its attention to the tender partially folded leaves of the coconut palm. According to Corbett (1932), the growth of the seedling plants is often seriously retarded and if the attack is severe and of a long duration, the plants may die.

He suggested spraying the attacked seedlings with lead arsenate as a measure of control.

BRONTISPA FROGGATTI *Sharp*

This is reported to be an important pest of coconut palms in the Solomon Islands and is also injurious to coconuts in New Guinea. The adult beetle is about 8 mm in length and 2 mm in width. The elytra are completely black except for a small portion adjoining the thorax, which is yellow ; the head and antennae are black. It attacks palms of all ages, although it is most severe in nurseries and young transplanted seedlings in the field. The adults and larvae feed on the surface tissue of unopened leaflets. The Tetrastichid, *Tetrastichodes brontispae* Ferr. and *Trichogramma nanum* Zehnt. were established in Solomon Islands for control of this pest and have proved effective parasites (Froggatt and O'Connor, 1941 ; Evans, 1952).

Froggatt and O'Connor suggested pouring nicotine sulphate solution down the opening central shoot, as a measure of control.

MELITTOMMA INSULARE *Fairm.*

Melittomma insulare Fairm., is a wood boring pest of coconuts in the Seychelles and northern Madagascar. It is a small beetle measuring from 7 mm to 17 mm. The beetle lays eggs in crevices in palms and the initial tunnels made by the larvae originate from the bole. The roots at this point die. The larvae thereafter tunnel inwards and upwards traversing the soft tissues. Brown (1954) reported that the larvae feed on fluid extracted from the parenchymatous tissues and not on solid wood. The infestations in individual palms generally culminate in their death.

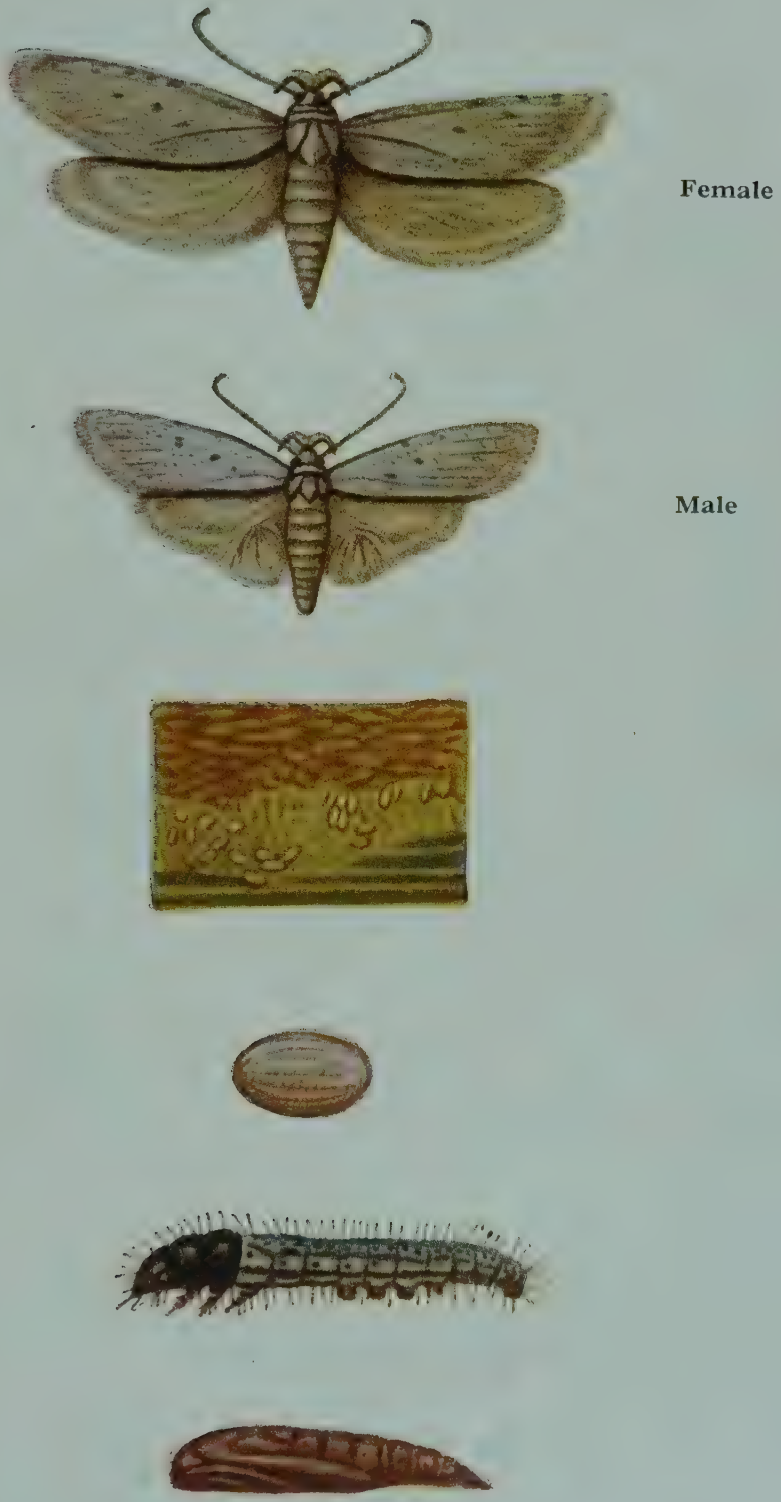
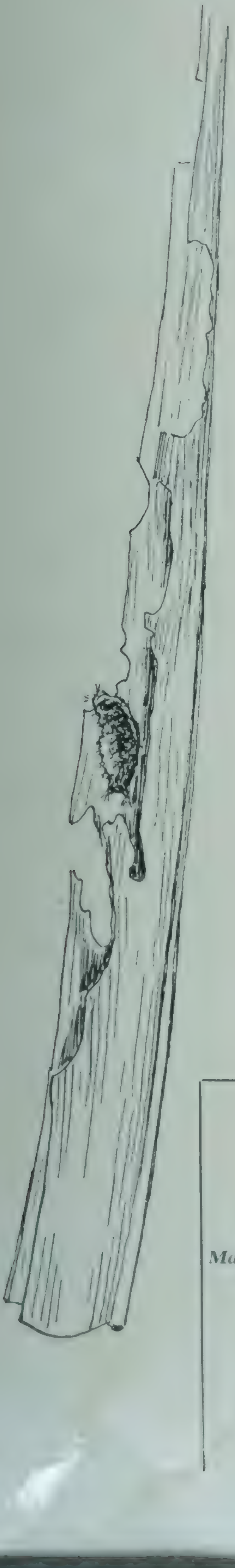

Female
Male

Fig. 100. *Nephantis serinopa*—different stages
(After Jayaratnam, 1941)



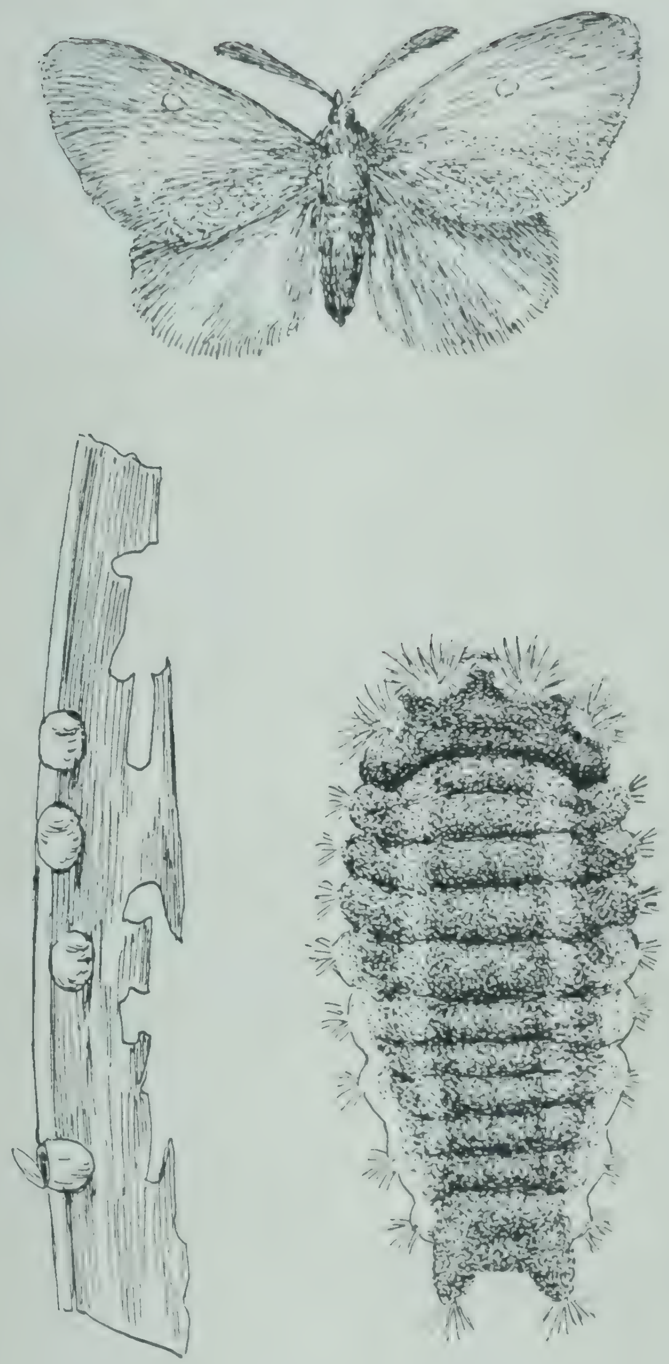
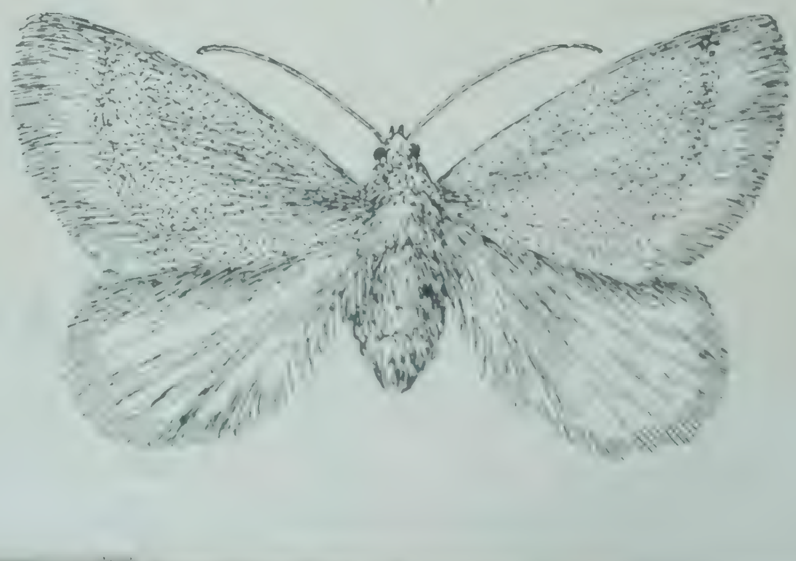


Fig. 101.
Contheyla rotunda — different stages

Fig. 102.
Macroplectra nararia



Brown (1954) found out that fumigation treatment was decidedly the most successful, while contact with insecticides only occasionally produced good results. Of the fumigants, para-dichloro-benzene was found to give the best results.

LEPIDOPTERA

NEPHANTIS SERINOPA *Meyr.*

The coconut caterpillar, *Nephantis serinopa* Meyr., is another serious pest of coconut palms in India, Ceylon and Burma. The larvae of the pest live on the under surface of the leaves in galleries made of silk and excreted matter and feed on the green tissues; the injury by numerous larvae causes the foliage to dry up and when many fronds are affected, the tree suffers considerable damage with the result that yield is materially reduced. Infested trees are easily recognised by the dried up patches in the leaflets and the deposit of fras on these parts.

The earliest record of this pest was made by Green in 1900 in Batticaloa district of Ceylon. In 1906-7 it attracted serious attention in Colombo district. In 1907, it was also recorded in Coimbatore on palmyra leaves. In India, the earliest record of its presence on the coconut leaves was made from Bapatla, Andhra Pradesh in 1909. In 1923, Ghosh recorded its presence throughout Burma.

In India the pest has been studied by Rao (1923, 1926), Ananthanarayanan (1929 and 1934), Ayyar (1940), Rao, Cherian and Ananthanarayanan (1948), Nirula *et al.* (1951) and Nirula (1955 and 1956). In Ceylon, Green (1906), Hutson (1922) and Jayaratnam (1941) have contributed some information on this pest.

Host plants

The principal host plant of *Nephantis serinopa* is the coconut palm. According to Rao *et al.* (1948) it is probably the palmyra palm *Borassus flabellifer*. *Naphantis* is found on palmyra palms, even in areas where coconut is not grown and it is quite likely that this insect has adapted itself to other palms. In India, the other host plants are the talipot palm *Corypha umbraculifera*, the wild date or toddy palm, *Phoenix sylvestris* and some ornamental palms.

Distribution

The pest has been reported in India right from Cape Comorin to Bombay on the West Coast and throughout the East Coast from Tinnevelly to Puri. It has also been reported from several places in the interior like Coimbatore, Salem, South and North Arcot and Chinglepet in the south and Patna in the north-east.

The pest is usually found in widely separated localities, and in each locality it usually disappears soon after it has begun to multiply, natural factors suppressing it completely. Under favourable circumstances however, it multiplies rapidly, and causes great damage. Such severe outbreaks occur more frequently in certain coastal regions of South India.

Seasonal history

On the West Coast of India, *Nephantis serinopa* is present throughout the year, but appears as a serious pest only during the hot months of March, April and May. If the south-west monsoon is delayed, the pest continues its activity and causes extensive damage. With the onset of the rain, the larval galleries of the pest get wet, and a high mortality due to fungal and bacterial attacks takes place. The ecological conditions during this time are favourable for the multiplication of the parasites and predators, which keep the population of the pest in check. It, however, does not disappear during the period, but its population is thinned down. After the rains, it again starts multiplying rapidly, but is kept under control by its natural enemies. From January it increases in large proportions and its parasites commence disappearing. By March the activity of the pest is at its peak and the infested palms put on their worst appearance.

On the East Coast of India, the pest is least active during the period of the north-east monsoon from September to December and is quite common during the hot and dry months of April, May and June. In the interior districts of South India, the pest is common during the dry months from January to May.

Description

Nephantis serinopa Meyr., belongs to the family Cryptophasidae. It was first described by Meyrick in 1905. The adult is a medium sized moth measuring in size from 10 mm to 15 mm with a wing spread of 20 mm to 25 mm. The head and thorax are light greyish-ochreous in colour. Forewings are elongated, pale greyish in colour, with some finely scattered blackish scales. The male moth is smaller with a slender abdomen ending in a short brush of scales, while in the female the abdomen is stouter and pointed at the tip. The male can be further distinguished by the presence of a conspicuous tuft of hair at the base of the hind wing.

The eggs laid by *Nephantis serinopa* are oval in outline, 0·6 mm to 0·8 mm long and 0·3 mm to 0·4 mm wide. When freshly laid they are creamy-white in colour, but gradually turn pinkish before hatching. The larvae are cylindrical, but a little compressed. The posterior end is slightly tapering. The anterior part of the body is broader than the rest of the abdomen. The head is small and curved inwards. The thorax carries a pair of legs on each segment. The abdomen is smooth and shining with long setae on the lateral sides and inconspicuous ones on the dorsal side. There are five larval instars which can be distinguished by differences in size and colour. The newly hatched larva is pale white in colour, but soon after, changes into greenish-yellow. It measures from 1·5 mm to 3·5 mm during the first instar. The colour changes to greenish and ultimately in the final instar it becomes light green. The size also increases to about 15 mm in length. *Nephantis* larva can be further identified by the presence of reddish-brown stripes, one on the dorsal side and two each on lateral sides.

Before pupation, the body of the larva shrinks and it becomes inactive, and this inactive stage is known as the pre-pupal stage. The pupae are somewhat flattened dorsoventrally, tapering posteriorly and blunt at the anterior end. These are light brown and translucent, becoming darker and more opaque as the development proceeds (Fig. ***100***).

Life history

The female moths deposit their eggs near the tips of the leaflets and very close to the old larval galleries. The eggs are generally laid on the older leaves, but sometimes in severe epidemics they might be found on the central shoots also. The eggs are very small and inconspicuous and unless very closely examined they are liable to be missed.

The young larvae, soon after hatching, move about in search of suitable feeding places. Before commencing feeding, the tiny larva makes a silken gallery under which it lives and feeds. These galleries are extended and covered with small pieces of leaf bitten off by the larvae and their excretions. *Nephantis* larvae are voracious feeders and the feeding scars may attain considerable lengths.

After completion of the larval period, the larva becomes slightly pinkish in colour and gets quite sluggish in habits. This pre-pupa selects a suitable corner of the larval gallery and starts spinning its cocoon. The cocoon consists of fine silken threads secreted from the silk glands and is oval in shape, with an opening at its anterior end to afford an easy exit for the moths. After completing the cocoon, the pre-pupa lies motionless for about a day, during which time a gradual change in form takes place. The pupa is attached to the cocoon by a circle of hooks on the cremaster, and when disturbed, rotates on its body axis. Emergence of the adult generally takes place in the early hours of the morning.

The adults of *Nephantis serinopa* are essentially nocturnal in habit. During the day time, they rest on the drooping leaflets of the coconut palms and sometimes on the stem of the palm. The period of greater activity is after dusk till it is very dark. The moths are not attracted to light. The strong winds generally prevalent in the coastal regions have no effect on the resting moths, but the flying ones may be carried to long distances. Light rain has no effect on the activity of the moths, but during heavy showers accompanied by strong winds, quite a number of moths are washed off from their resting places. The mating generally takes place during the night, following the day of emergence, but sometimes it may be delayed by two or three days. The oviposition starts on the day succeeding pairing and it continues for about two days. The total number of eggs laid by a single female varies from 59 to 252 with an average of 137 (Nirula, 1955). Before the female moth dies there is a post-oviposition period varying from a few hours to two days. The moths are not capable of mass migration, and are generally introduced into new areas by various human agencies. The coconut leaves along with *Nephantis* larvae and pupae are carried unintentionally to far off places and moths emerging out of them start fresh infestations.

According to Nirula *et al.* (1951), the total duration of the life cycle from egg to adult takes about two months on the West Coast. The incubation period is about five days, the larval period on an average forty-two days and the pupal period about twelve days. The potential rate of multiplication is quite high and in the absence of controlling factors, a single pair could theoretically give rise to about eight hundred thousand adults in the short period of six months.

Parasites and Predators

This insect is found subject to attacks of some natural enemies. The more important of these are the Vipionid, *Apanteles taragamae* Vier., the Braconid, *Microbracon brevicornis* Wesm., the Bethylid, *Perisierola nephantidis* Meus., and the Elasmid, *Elasmus nephantidis* Roh., all attacking the *Nephantis* larvae; the Eulophid, *Trichospilus pupivora* Ferr., the Chalcids, *Stomatoceras sulcatiscutellum* Gir., and *Brachymeria nephantidis* Gahan and the Ichneumonid, *Xanthopimpla punctata* F., all parasitising the host pupae. The mite, *Pyemotes ventricosus* Newport attacks the eggs, larvae and pupae of the pest. The other predators are the Carabid beetles, *Parena laticincta* Bates, and *Phlaeodromius nigrolineatus* Chand., the reduviid bug, *Sphedanolestes aurescens* Dist., and some species of ants. Certain species of spiders are also met with on the coconut leaves infested by *Nephantis.*

Besides the parasites and predators mentioned above, the larvae and pupae of *Nephantis* are quite often killed by fungal and bacterial infections during the monsoon period.

Control

Mechanical. As soon as the first signs of *Nephantis* attack are noticed, it is very important that prompt measures are taken to check this pest before it becomes serious. The simplest remedy in an early stage of the attack is to cut off and burn all infested leaves or parts of leaves which show any traces of larval galleries. The infested material must be burnt immediately. There are certain limitations to the adoption of this method, but in cases of stray infestations in the isolated plantations, the pest can be checked from spreading.

Biological. As already stated, the coconut caterpillar, *Nephantis serinopa* is attacked by a number of parasites and predators. Some of these parasites are amenable to laboratory breeding and multiplication. These parasites are the Braconid, *Microbracon brevicornis* Wesm.; the Bethylid, *Perisierola nephantidis* Meus., the Elasmid, *Elasmus nephantidis* Roh., and the Eulophid, *Trichospilus pupivora* Ferr., which are bred in the laboratories in large numbers and released in the infested areas (Fig. ***103***).

The severe infestation of 1924-25 in Malabar and South Kanara in India was brought under control by extensive liberation of the parasites, and the pest was brought down to the irreducible minimum by 1931 (Rao *et al.* 1948). Similarly another serious outbreak in the deltaic areas of West and East Godavari was brought under control by intensive colonisation of parasites for a period of over two years (Dharmaraju, 1952).

However it may be mentioned here that when it comes to a question of adopting the biological method as a primary measure of *Nephantis* control, arrangements of a more organised nature will be found necessary, if substantial and sustained benefits are to be derived. To carry out a regular campaign, the most important thing necessary is, a plentiful supply of the suitable parasites ready for liberation in the infested areas. The liberation of only a few individuals has the disadvantage of these few separating from one another and spreading far away, thus preventing the chances of union of sexes and multiplication of the species. Another defect one has to guard against in such a measure is the probable contingency of the parasites being starved or destroyed when liberated in any tracts, either for want of sufficient food or due to sudden and unusual climatic changes. To guard against these and other incidental defects, the best procedure would be to have the parasites bred in large numbers and then distributed in batches after ascertaining the proper stage of development of the pest and the prevailing ecological conditions.

Insecticidal. Control of *Nephantis serinopa* with the help of insecticides was tried at the Central Coconut Research Station, Kayangulam, and Nirula *et al.* (1951) obtained successful control both in the laboratory and the field, with 0·2 per cent DDT spray. In dry areas, 0·2 per cent BHC spray also gives equally good results, but in regions of heavy rainfall, BHC was found to lose its residual toxicity very soon.

As a prophylactic measure of control, spraying of the palms with 0·1 per cent DDT has been found to give good results on the West Coast of India.

CONTHEYLA ROTUNDA *H.*

The leaf eating slug caterpillar, *Contheyla rotunda* H., is a pest of sporadic occurrence, but at times it is capable of causing considerable damage to coconut palms. During severe outbreaks, the larvae of the pest completely defoliate the leaves, and sometimes spathes and nuts are also attacked. This defoliation causes heavy reduction in the yield of nuts.

The first record of its occurrence as a pest of coconut palms in India was made in South Malabar during February, 1916. Soon after this incidence of attack, Ayyar (1917) published a short account of the pest and the damage caused by it in a number of places in Cochin. A very severe outbreak was recorded by Nirula *et al.* (1954) in an island in Ashtamudi lake in South Kerala.

The insect is quite common throughout Travancore-Cochin, Malabar, South Kanara and North Kanara. Anstead (1919) has reported it from Wynaad. But according to Nirula *et al.* it is more common in the coastal and littoral tracts of the West Coast of India, and in these areas the insect is mostly confined to isolated pockets. There is no record of its presence on the East Coast of India.

Contheyla rotunda breeds mainly on the coconut palms, but in cases of severe outbreaks, the larvae of the pest may be found feeding on banana leaves also. Wild arrowroot plants and tea bushes have also been reported as alternate host plants.

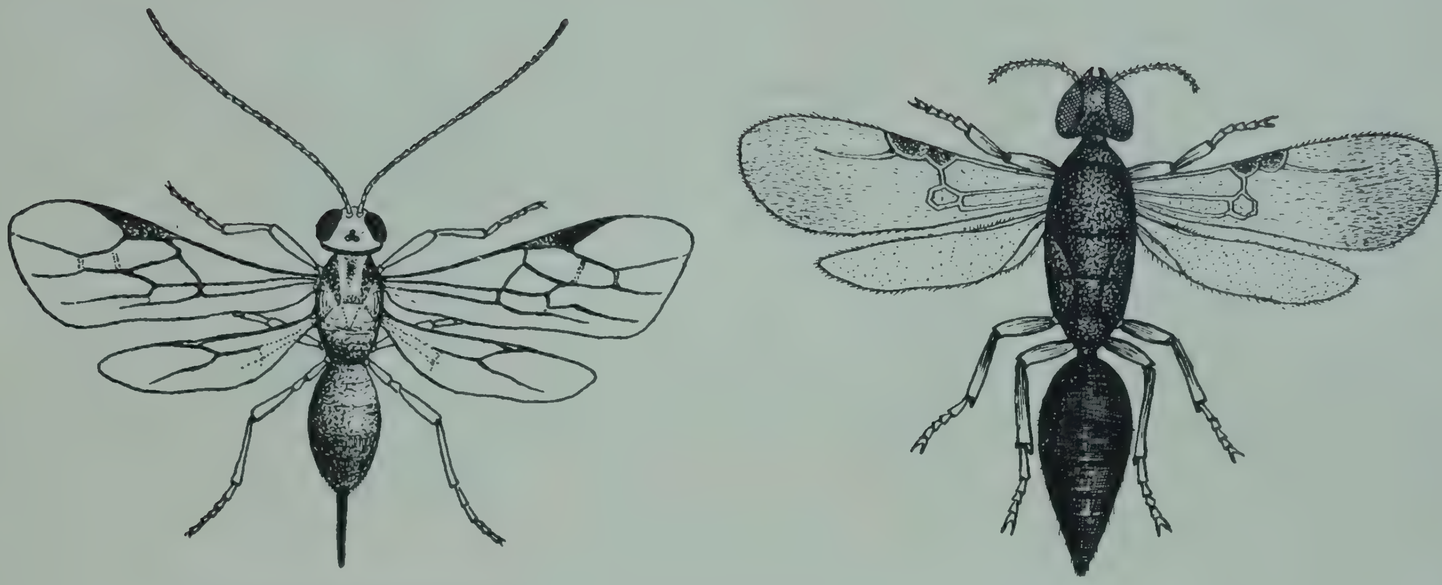
The adult (Fig. ***101***) is a small inconspicuous moth, about half a centimetre in length and having a wing expanse of about one centimetre. The colour of the moth varies from greyish-brown to dark grey. The moths keep their wings roofed up. The antennae are plumose in males and filiform in females. The eggs are elliptical and compressed and are laid singly on the underside of the leaflets in small batches. The number of eggs laid by a single female varies from 62 to 324 and with an average of 215 (Nirula *et al.* 1954). The eggs hatch in about five days and the young larvae come out of the egg shells by bursting them open. The larva is a slug-like creature covered all over with spines and with two narrow grey stripes running on the dorsal side. Young larvae feed on lower epidermal tissues, but as they grow up they start feeding right through the leaf at the edge, beginning from the farthest end of the pinnae. The larval period on the West Coast varies from 27 to 48 days and with an average of 34 days. Before pupating, the larvae spin dense cocoons of brown silk impregnated with a loose white powdery substance. The pupal period which is spent inside the cocoon varies from ten to fourteen days. The moths come out of the cocoons by pushing aside the opercula. Mating takes place during the morning following the day of emergence and oviposition continues for about two days. The total duration of the life cycle of *Contheyla rotunda* varies from 40 to 68 days and takes on an average 52 days.

Thompson (1943) recorded a Braconid, *Rogas* sp., as a parasite of *Contheyla* larvae. Nirula *et al.* (1954) in addition to this Braconid, observed a Chalcid, *Antrocephalus* sp., and a Chrysidid, *Chrysis* sp. parasitic on pupae of *Contheyla rotunda*. They report having successfully controlled this pest when it broke out in epidemic proportions in a small island in the Ashtamudi lake, Quilon district, Kerala by spraying the foliage with 0·1 per cent DDT.

MACROPLECTRA NARARIA *Moore*

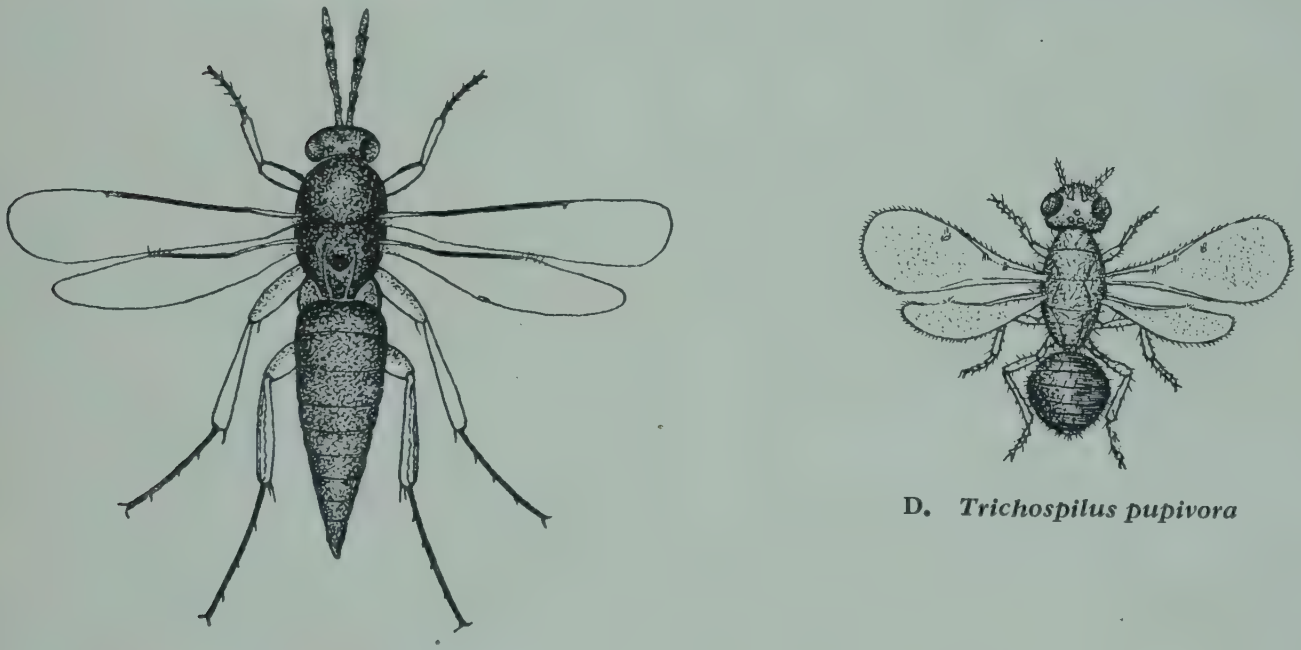
On the East Coast of India, the spiny slug *Macroplectra nararia* Moore, occasionally attacks the coconut palms and causes extensive damage to the leaves. According to Nirula (1955), it has recently assumed major proportions in the East and the West Godavari districts of Andhra. On coconuts, it is more common during the summer months and is naturally controlled with the commencement of the rains. Hampson (1892) recorded it from Dharamsala, Mhow, Nilgiris and Ceylon, while Fletcher (1919) reported its presence throughout southern India and Ceylon. Besides coconut palms, Fletcher reported it as a pest of tea in Ceylon and hedge plants, *Sideroxylon subsilatum* and *Pithecolobium dulce* in Coimbatore. Recently Evans (1952) has stated that it is the most injurious of several Limacodids that feed on tea in Ceylon.

The adult is a pale brownish-ochre coloured moth (Fig. ***102***). The basal two-thirds portion of the fore-wing is red in colour, while the outer border is brown. The eggs which are laid singly on both sides of the leaves hatch in about four to five days. The full grown larva is 8 mm to 11 mm in length and is yellowish-green dorsally and pinkish ventrally. The larva has a subdorsal series of red-tipped spinous tubercles with very short spines. The tubercles at each end are long and those at the posterior end are the longest. The larva is strongly mandibulate and is devoid of pro-legs. According to Ballard and Rao



A. *Microbracon brevicornis*

B. *Perisierola nephantidis*

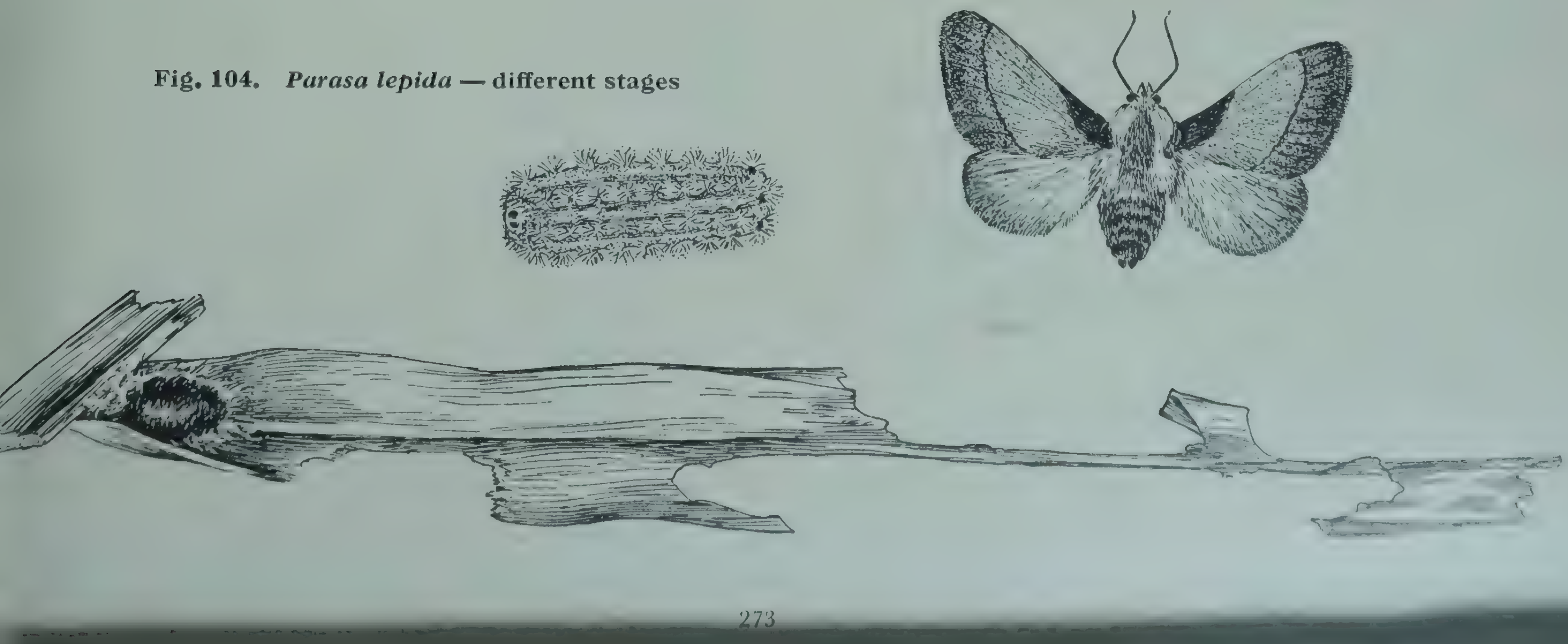


C. *Elasmus nephantidis*

D. *Trichospilus pupivora*

Fig. 103. Parasites of *Nephantis serinopa*

Fig. 104. *Parasa lepida* — different stages



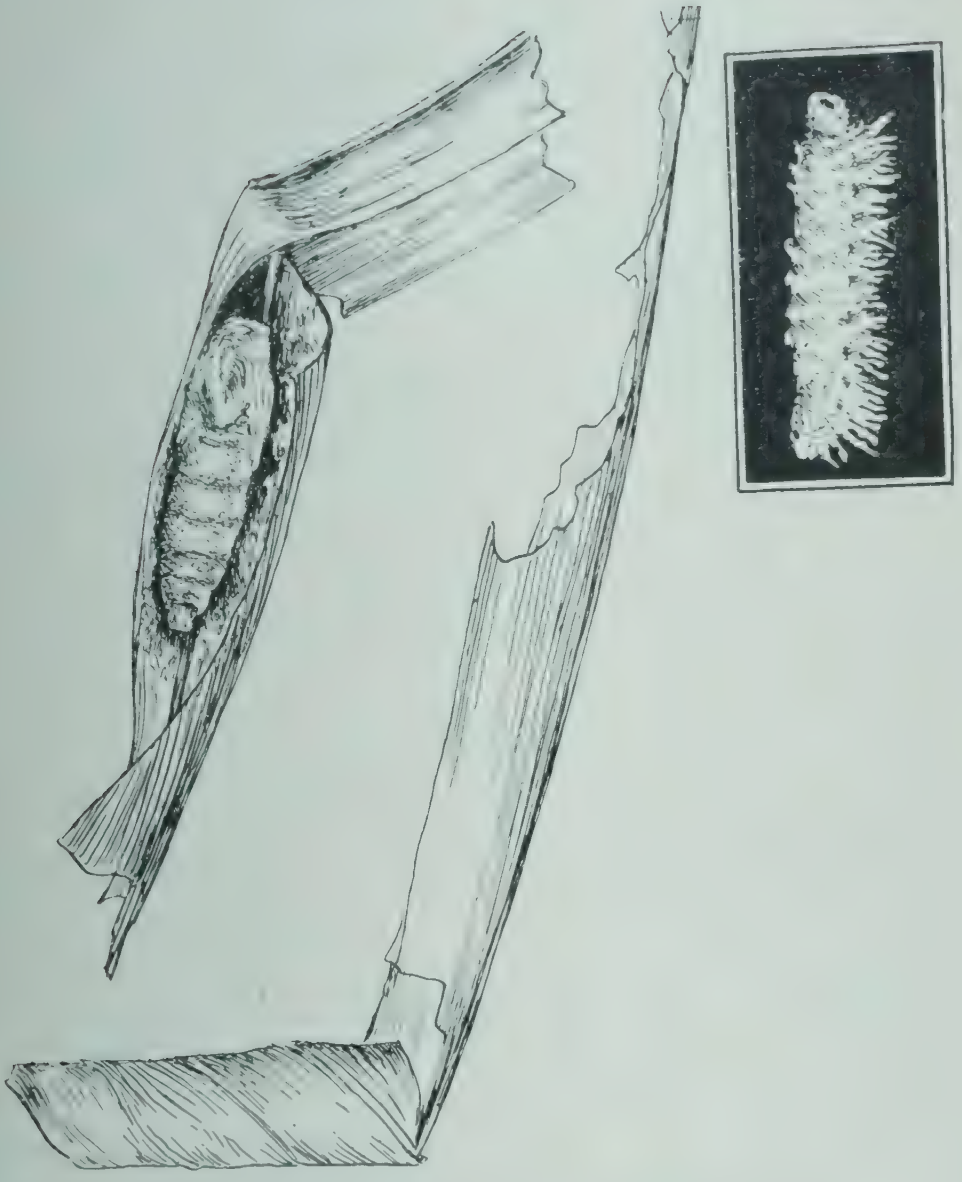
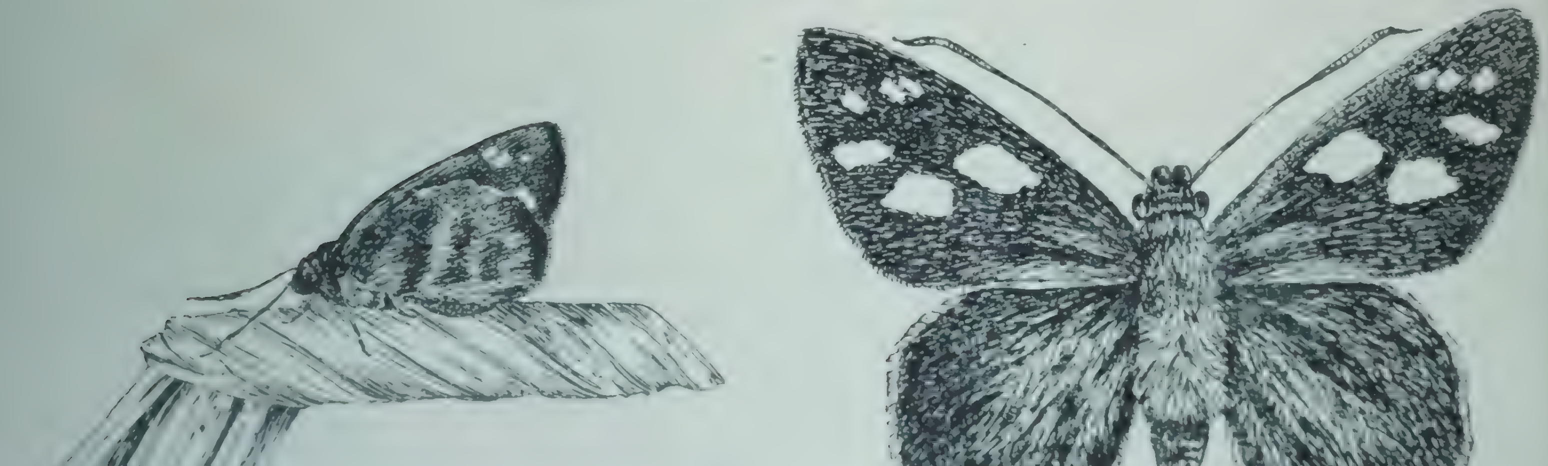


Fig. 105. *Gangara thyrsis* — caterpillar and pupa

Fig. 106. *Gangara thyrsis* — Adult



(1921), the larval period on an average is 31 days. The purplish-brown cocoon is spherical and is kept in place between the leaflets by a tangle of silk threads. The pupa is about 6 mm in length, stout and roughly oval. The pupal period according to Ballard and Rao was on an average 15 days at Coimbatore, and the average life of the moth appeared to be five days.

The pest is attacked by a number of natural parasites. Gadd *et al.* (1948) have recorded five species of Euplectrine Eulophids in Ceylon, but of these, the commonest is *Neoplectrus maculatus* Ferr. According to Dharmaraju (1952), the pest is attacked by a Braconid in its larval stage and by a Chrysidid and two different species of Chalcids in its pupal stage. Fletcher reported that spraying with lead arsenate was found successful for the control of this pest at Coimbatore. Recently Dharmaraju tried spraying of the coconut palms attacked by *Macroplectra* with 0·2 per cent DDT and the results obtained were reported to be satisfactory.

PARASA LEPIDA *Cram.*

Parasa lepida Cram. is another Eucleid which infests coconut palms. Like *Contheyla rotunda* it can, under favourable environmental conditions assume an epidemic form. It is always present in coconut gardens on the West Coast, but severe infestations occur only sporadically. The larvae feed on the coconut leaflets leaving only the mid-ribs. Young trees about six to ten years of age are preferred and the attack generally becomes severe during the rainy months of June to September. Besides coconut palms, this pest attacks castor, young mango leaf, banana, rose, pomegranate, palmyra palm and some other plants.

The moths have green wings fringed with dark brown patches and can be seen resting on the leaflets with their wings kept roofed over. The eggs are laid in batches on the underside of the leaflets and appear as flat scale-like patches. The eggs hatch in about a week into small white grub-like caterpillars. The caterpillars popularly known as slugs are thick, flat and yellowish-green in colour with a greenish-blue stripe dorsally and two yellowish-green stripes laterally one on each side of the body (Fig. ***104***). They are provided with a series of tufts of spines on the body which are highly irritant in action. The caterpillars on hatching, feed gregariously for a few days and disperse later. Pupation takes place after about five weeks inside hard shell-like greyish cocoons, which are also equally irritant. Hundreds of such cocoons can be seen in groups on the tree trunks. After about four weeks, an operculam opens at one end of the cocoon and the adult moth emerges.

The larvae of *Parasa lepida* Cram., are heavily parasitised, so much so that the majority of caterpillars hatching from a batch of eggs fail to reach maturity. These parasites are *Clinocentrus* sp., *Stomatoceras ayyari* G., and *Eurytoma parasae* G. (*Mem. Dept. Agric. Madras* 1954). An interesting predatory caterpillar, *Phycita dentilinella* H., has also been recorded inside the cocoons of this pest, destroying the pupae (Ayyar, 1940).

The control of this pest can be easily effected in the earlier stages by clipping the portion of leaves with the young caterpillars when they are gregarious and destroying them. The cocoons also can be destroyed mechanically. Precautions should be taken that operators do not come in contact with the caterpillars or the cocoons. Corbett (1932) and Venkitasubban (1938) have suggested the spraying of infested palms with lead arsenate, as an effective measure for the control of the pest. Recently dusting with 5 per cent BHC also gave satisfactory control (*Mem. Dept. Agric. Madras* 1954).

GANGARA THYRSIS *Moore*

This is a Hesperiid butterfly, the caterpillars of which attack young coconut seedlings one to two years old. According to Fletcher, this is a common species throughout the plains of India, Burma and Ceylon. Corbett has reported its presence from Malaya also. In India, Ayyar reported it as a pest of coconut nurseries in South Kanara.

The butterfly has a brown body with a wing expanse of about 80 mm (Fig. ***106***). The colour of the wings is chocolate brown with six yellow spots on the fore-wings; three larger ones are situated near the middle and three smaller towards the apex. The eggs are laid on the leaves in irregular masses, which hatch in about a week. Soon after hatching, the young caterpillars are seen eating the leaves. About two days after hatching, they construct tubes by uniting the edges of the leaflets with strong whitish coloured silken threads (Fig. ***105***). Inside these tubes they live in concealment eating from the edges of the leaflet, leaving behind only the mid-rib. The full grown caterpillar is pale green with reddish markings, but the colour is generally concealed by numerous long, prominent, white, waxy filaments. The larval period lasts for about five weeks and pupation takes place in the same leaf folds. The pupae have a habit of vibrating and striking against the inner surface of the folds when disturbed. The pupal period lasts for about ten days.

This pest is attacked by a number of parasites and predators, and they keep its population generally under control.

The damage caused by this pest can be reduced by collecting the caterpillars and pupae or by cutting off and burning the badly attacked leaves. Spraying of the badly attacked seedlings with 0·2 per cent DDT or 0·2 per cent BHC would also be effective.

SUASTUS GREMIUS *Fb.*

Suastus gremius Fb. is another Hesperiid butterfly, the larvae of which feed on various palms, like palmyra, coconut and date. According to Fletcher (1917), it is a minor pest, but sometimes occurring in considerable numbers. Nirula (1955) reported that the larvae of the pest feed on the coconut leaves and at times cause considerable damage to the palms on the West Coast of India. Fletcher (1914) has recorded it from Bangalore, Godavari, Coimbatore and other palm growing tracts of India.

The butterfly has a wing expanse of about 40 mm and is chocolate-brown in colour, with light yellow spots on the fore-wing (Fig. ***107***). Upright eggs, laid singly on the leaves, hatch to pale green caterpillars with five pairs of sucker feet. The larvae are usually smooth and elongate, tapering evenly to either end. The head is large and oval, the pro-thorax is distinctly compressed behind the head, giving the appearance of a neck. The body is slightly flattened, the inter-segments are not constricted, and the sucker feet are flat. The full-grown larva is green with a prominent dark green mid-dorsal line. The larva lives in tubes formed by rolling up portions of palm leaves. When full fed, it closes the ends of this tubular cell with silk and changes to a yellowish pupa.

For the control of this pest, the caterpillars and pupae should be collected and destroyed, and the badly attacked leaves containing the caterpillars and pupae should be burnt.

BRASSOLIS SOPHORAE *L.*

The larvae of this butterfly cause severe injury to coconut palms in British Guiana and Trinidad.

The eggs are laid in masses upon the trunks of the coconut palm or on underlying debris. The young caterpillars are brownish red with pale yellowish stripes running along the length of the body, and they have large, smooth, shiny, dark reddish heads. When full grown, they become dark brown with longitudinal stripes of dirty whitish or pale brown colour. The caterpillars are gregarious and feed only at night. During the day, they collect in large ' nests ' made by spinning leaflets together to form shelters. The larvae also conceal themselves in the heart of the palms at the base of the leaves. The pupal stage is passed in any situation that affords shelter. In the adult butterfly, the fore-wings are brown with orange yellow bar across the centre, the hind wings are brown tinged with orange, the thorax is brown and the abdomen is reddish. With wings expanded they measure from 6 cm to 7 cm.

Severe infestations, which result in the loss of coconut crop and the death of many palms usually occur during the wet season.

Guppy (1911) suggested the mechanical removal of caterpillars and pupae of the pest as a measure of control.

BATRACHEDRA ARENOSELLA *Walk.*

This is a Tineid moth, commonly known as ' Lesser coconut spike moth '. The larvae of *Batrachedra arenosella* Walk. are often found gnawing the male and female flowers of coconut palms, and the latter frequently develop a distinctly black appearance. At present it is of sporadic occurrence in India, but there might be possibilities of its developing into a serious pest under optimum environmental conditions. Corbett (1932) recorded 6·5 per cent loss to the female flowers in some areas in Malaya.

The eggs are laid by the female moth in the linear depressions of the green spathe and the larvae bore into the unopened inflorescence and attack female and male flowers alike. The damage done is considerable, a large percentage of the female flowers being bored into. The full fed caterpillar pupates in a cocoon of white silk at the bottom of the spathe, the damage to which is apparent only when it opens.

CYCLODES OMMA *V.*

Cyclodes omma V. is a Noctuid moth, the caterpillars of which bore into the tender nuts, feed on the contents inside and cause them to drop (Fig. *108*). The insect is not very commonly met with on the West Coast of India, but when it does occur in a tree, it causes considerable damage. According to Venkitasubban (1938) it seems to possess potentialities of turning out to be a severe pest.

ARTONA CATOXANTHA *Hamps.*

The coconut leaf moth, *Artona catoxantha* Hamps. (zygaenidae) is a very serious pest of coconut palms in Malaya and Indonesia. Severe infestations occur at intervals of from two to six years. During outbreak years, all but the youngest leaves of coconut palms may be entirely destroyed.

The adult moth is 7 mm to 8 mm in length with wing expanse of 13 mm to 16 mm. Dorsally it is uniformly chocolate brown in colour, while ventrally it is yellow. The eggs are laid singly on the under surface of the pinnae of the leaves. The young caterpillars feed on the lower epidermis of the leaflets. The feeding marks are characteristic, being straight and having the appearance of ladders. The older caterpillars, in addition, may also eat the edges of the leaflets. Cocoons are mostly found on the lower surface of the leaflets. The average life cycle according to Corbett (1932), in Malaya was 37 days while according to Vecht Vander (1950), it was 33 days in Indonesia.

Several parasites have been recorded by Corbett in Malaya and Vecht in Indonesia, and these parasites generally keep the pest population in control, but at times this equilibrium between the pest and its parasites is disturbed, when the pest multiplies rapidly and completely defoliates the palms.

Corbett examined the various recommendations made for the control of this pest and felt that at the commencement of outbreaks in small areas, the attacked leaves should be cut and burnt, while in cases of widespread outbreaks he advised to keep reliance on natural methods of control effected by the Tachinid, *Ptychomiya remota* Ald., and other parasites. Vecht Vander (1950) reviewed the development of the control measures and described spraying of the trees with derris powder suspensions, which had given successful results in early stages of attack.

LEVUANA IRIDESCENS *B.-Bak.*

This is a Zygaenid moth, the caterpillars of which feed on the foliage of coconut palm and cause heavy damage. In 1922, the insect spread to some islands in Fiji and by 1925, it had increased to such an extent that the coconut industry, on which the islands very largely depended, appeared to be threatened with extinction.

The adult moth is dark metallic purple in colour excepting the abdomen which is ochreous. It measures from 13 mm to 17·5 mm in length. The eggs are laid in clusters on the coconut leaves, usually on the under surface. The caterpillars are slug-like in appearance and beset with tufts of short stout hairs. When feeding on a leaf, they appear white, with two black lines running the length of the body on the dorsal side. The larvae feed on the surface tissues of the coconut leaves and the feeding marks are generally parallel to the course of veins. Pupation takes place in cocoons and the pupae are somewhat flattened dorso-ventrally. The duration of the life cycle from laying of the egg to the emergence of the adult was on an average 43 days in the hot season and 51·5 days in the cool season in Fiji. Tothill *et al.* (1930) carried on a regular campaign for the control of this pest, studied its life history, parasites and predators, and introduced a Tachinid *Ptychomiya remota* Ald. from Malaya and obtained effective control in Fiji.

HOMOPTERA

ASPIDIOTUS DESTRUCTOR *Sign.*

The Coconut Scale, *Aspidiotus destructor* Sign. is a well-known pest of several crops and is present in most of the tropical countries. In India, outbreaks of this scale occur periodically, chiefly during the hot months of the year. The pest feeds mainly upon the underside of the leaflets. In severe outbreaks on coconut palms, the insect multiplies with such abundance that it forms a continuous yellow crust all over the underside of the leaflets. It causes premature death of the leaflets by sucking their sap and obstructing the stomatal openings. Attacked leaves first turn yellow, then wither and die, and a reduction in the vitality of the whole tree results.

The pest has been recorded causing damage to coconut leaves in India by Ayyar (1919 and 1940), Fletcher (1919), Venkitasubban (1938) and Nirula (1955). In the Philippines, Copeland (1931) described it as a very serious pest of coconut palms in Negros. Copeland also reported the spread of this pest to Polynesia where it was doing great damage to coconut palms in some of the islands. Taylor (1935) published a full account of the campaign against this coccid in Fiji. It is reported as a serious pest of coconut palms in Ceylon (Hutson, 1933) and in Indonesia. However, in Indonesia, Reyne (1947) has mentioned that the species of the coccids causing severe damage was *Aspidiotus destructor rigidus*. In Malaya, Corbett (1932) reported *Aspidiotus destructor* as the most common scale insect on coconuts, but did not record it as a serious pest. A notable outbreak of this insect occurred in Mauritius in 1927 and many coconut palms died as a result of attack.

The female scale is nearly circular in outline, semi-transparent and pale brown in colour. The species according to Taylor (1935) is oviparous, and the eggs hatch under the scale giving rise to active young ones. They crawl out of the scale and move about looking for a suitable place to settle. These very small, oval, pale yellow crawlers affix themselves on the underside of the leaves by means of their rostra, and never move again. The duration of the free living period varies from 2 to 48 hours (Taylor). Soon after settling, they cover themselves individually with a transparent film of waxy material. The appendages are lost at the first moult. Till the middle stage of the second moult, there is no difference in the appearance between the sexes, both the male and female being pale yellow, but after this the male insect becomes reddish. A difference in shape is noticeable too, the male becoming elliptical at about this time, while the female is roughly circular. The males remain small and oblong, feeding and moulting for the second time into the pupal stage. The adult winged male, emerges from the pupa and escapes out to crawl actively and occasionally to fly. The female scale unlike the male, continues its growth after the second moult and does not change appreciably in form. Growth is rapid in the third instar and soon after the growth ceases, oviposition commences. When full grown, the female is merely a sac of eggs, generally flattened and nearly circular.

Oviposition continues for nine days and about 90 eggs are laid at regular intervals in batches of three or four in moderately quick succession (Taylor). The female rotates under the scale as it oviposits. The total life cycle from oviposition to the emergence of males is 32 days and females 34½ days according to Taylor (Fig. ***109***).

The pest spreads through transportation of scale-infested materials by human agencies. Insects, birds and fruit-bats may also carry the scales adhering to them from tree to tree. The young crawlers may move to the adjoining trees and the wind may also help in the spread of this pest.

Aspidiotus destructor Sign. is attacked by a number of parasites and predators, and of these, the predatory Coccinellid beetles are very important. Attempts have been made from time to time for obtaining the control of this pest by the introduction of these Coccinellid beetles. Successful control of this pest was obtained in Fiji by the introduction of *Cryptognatha nodiceps* from Trinidad (R.A.E. *17* : 33). In Mauritius, several parasites and predators were introduced from Java and Ceylon to control it. Of these, the most successful have been the Coccinellid, *Chilocorus politus* Muls. and *C. nigritus* (R.A.E. *34* : 165). In Ceylon, it is partially controlled by *C. nigritus* and other natural enemies (R.A.E. *21* : 361). In the Gold Coast, it is said to be controlled at times by a fungus *Nectria diploa* (R.A.E. *2* : 141, 670).

Lime-sulphur spray has been used since a long time for the control of the scale insects. But recently spraying with Parathion has given quite satisfactory results. Parathion at 0·025 per cent is generally used for the control of scale insects.

HETEROPTERA

AMBLYPELTA COCOPHAGA *China*

This is a Coreid bug which causes injury to coconut inflorescences in the Solomon Islands. The bug punctures the female flowers and young nuts and sucks out juice from them, with the result that a considerable number of female flowers and immature nuts fall off prematurely.

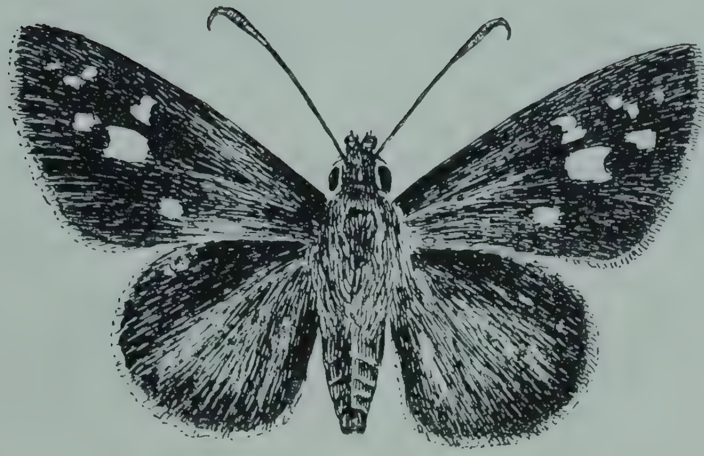
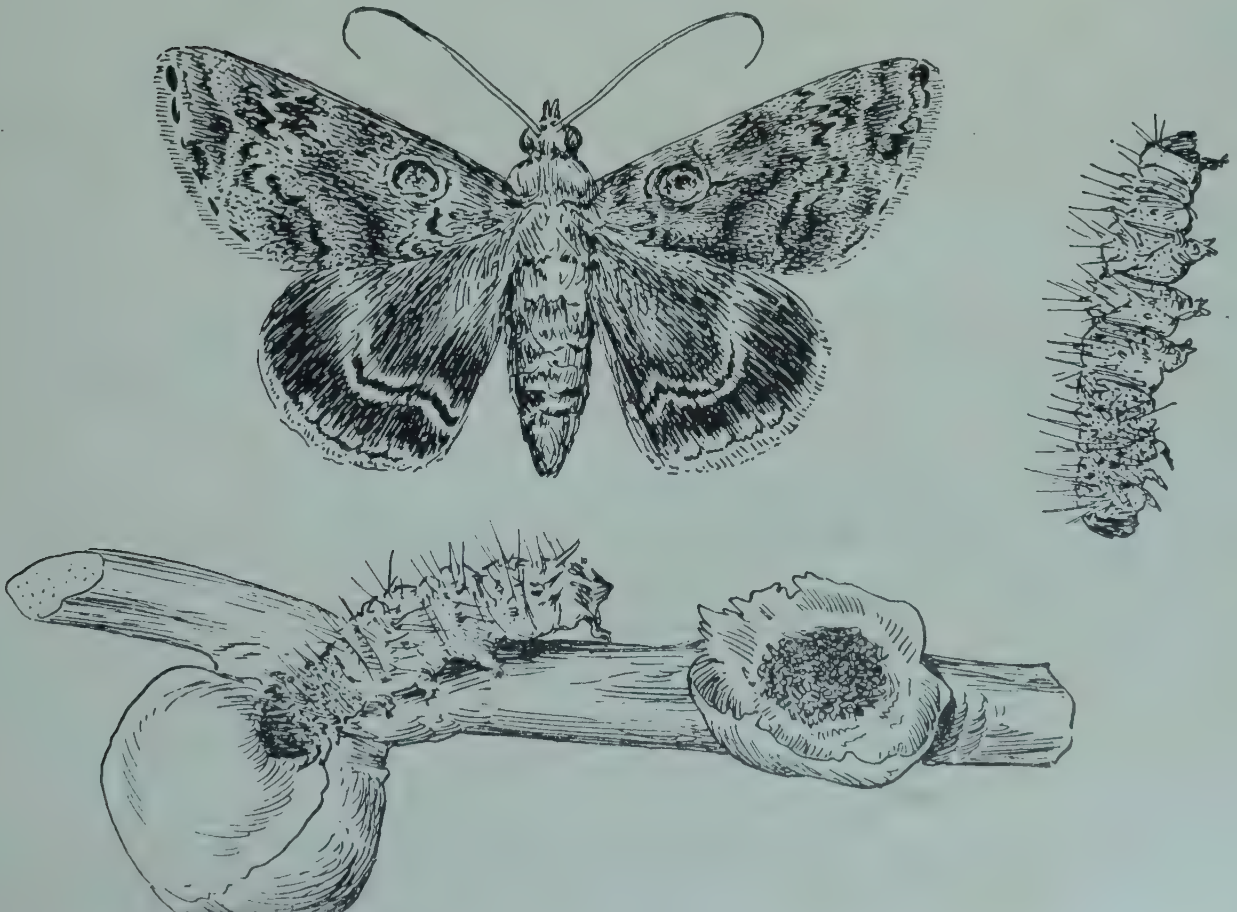


Fig. 107. *Suastus gremius*

Fig. 108. *Cyclodes omma* — larva and adult



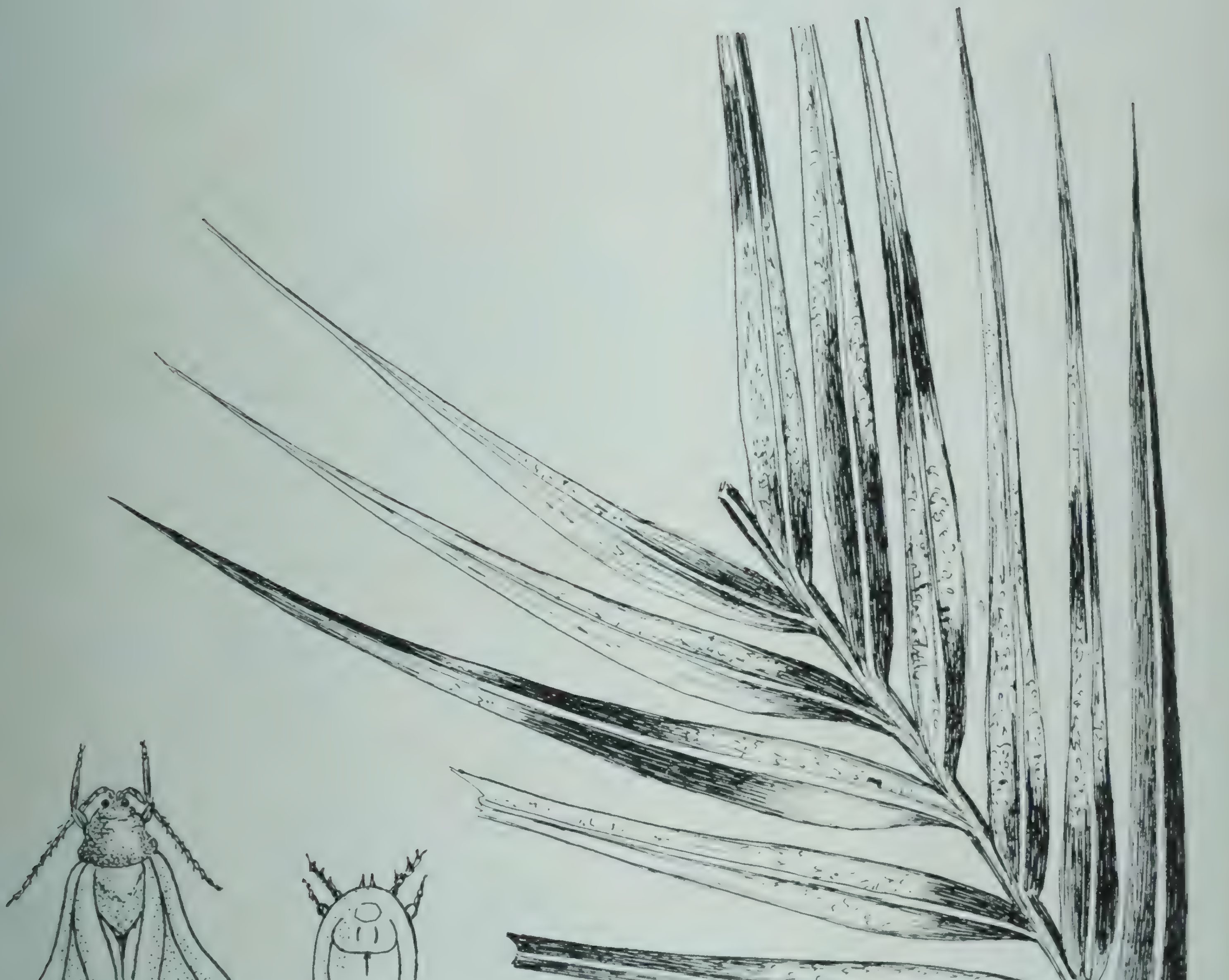


Fig. 109. *Aspidiotus destructor*

It has been reported that the ants, *Oecophylla smaragdina subnitida* Emery and *Anoplolepis longipes* Jord. control the insect when present but that they may be replaced by other ants *Pheidole megacephala* Fabr. and *Iriodomyrmex myrmecodiae* Emery which do not affect the numbers of the bug. During a visit to the Solomon Islands in 1948, Leach and O'Connor observed that the ant *Oecophylla* had recovered much ground in some of the coconut plantations, from where it was being gradually driven out before the war (O'Connor, 1954). In consequence, palms which were out of production for several years were bearing very heavy crops, as *Oecophylla* controlled the bug. O'Connor concluded that the growth of certain plants, mainly creepers which covered the plantation floor and provided a bridge for *Oecophylla* from trunk to the ground has enabled the beneficial ant to overcome the harmful species, *Pheidole megacephala* Fabr. It is also believed that the aerial spraying with oil emulsions of DDT by the U.S. forces has helped in stopping the premature nut-fall (O'Connor, 1954).

PSEUDOTHERAPTUS WAYI *Brown*

The Coreid bug, *Pseudotheraptus wayi* Brown, is widespread in the coastal region of British East Africa, where it severely damages developing coconut fruits.

According to Way (1954), the female may lay over 100 eggs and there are five nymphal instars, covering in the field about nine generations in a year. Female coconut flowers and young nuts may be destroyed by a single feeding puncture, and one bug may make over two hundred punctures in its life time. Way found out that a population density of less than two per palm may cause severe damage. He showed that *Oecophylla longinoda* Latr. protected the palms against the Coreid, but other ants such as *Pheidole* sp. *Anoplolepis longipes* Jerd. and *Crematogaster* sp., were antagonistic to *Oecophylla* and failed to control the bug.

Recently Vanderplank (1954) obtained very satisfactory control of this Coreid bug in Zanzibar by aerial spraying of coconut palms with 30 per cent DDT in Savacide fat at a rate of ¾ gallon per acre.

ORTHOPTERA

SEXAVA *Sp.*

Six species of Tettigoniids cause severe defoliation and loss of yield in coconut in New Guinea and the Solomon Islands but the more important of these are *Sexava nubila* Stal, and *S. novaeguineae* Brancsik. The eggs are laid in the ground or on the epiphytic growths on the trunks of palms. The adults feed at night or on dull days. An Encyrtid parasite, *Leefmansia bicolor* Waterston, has been introduced into New Guinea from Amboina.

The possibilities of controlling these insects by aerial spraying have been investigated but do not appear practicable under the present conditions. In the tropics, power dusting or spraying from ground level has proved difficult owing to irregularities of terrain, isolated nature of many affected plantations and difficulties in obtaining suitable machinery that will work effectively. (*Rep. Sixth Ent. Conf. Lond.* 1954: 180-81). Soil treatment against emerging hoppers and treatment of basal portions of palm trunks against ovipositing females have shown some promise of control.

GRAEFFEA *Sp.*

From time to time coconut stick insects *Graeffea* Sp. (*Phasmidae*) have been reported to cause severe injury to coconut palms in Samoa and Fiji. Outbreaks are usually confined to comparatively small areas. The insects devour the green tissues of the coconut fronds, and where the attack is severe, palms may be completely defoliated and even killed. Recently O'Connor (1954) has recorded an Eupelmid parasite of the eggs, which appears to be commonly distributed in Fiji.

He reported that control by applying sticky bands to palm trunks in Fiji has been unsatisfactory. Similarly power dusting with BHC was also not very effective, largely because of continuous wind and improper dusting machines. It was observed that most of the eggs of the Phasmids fall to the ground, but a few lodge in the leaf axils and nymphs hatch out of them. This probably explains the failure of sticky bands.

ISOPTERA

TERMITES

The termite is another important pest of the coconut palm. The most common species present in the coconut estates on the West Coast of India is *Odontotermes obesus* Ramb. The termites generally attack seedlings in the nursery growing on soils other than sandy, and appear to be attracted by the husk of the nut. Coconut seedlings may be attacked either through the base of the seednut or at the collar portion. The wilting of the central shoot is usually the first visible symptom of attack, and this is often followed by the death of the seedling. According to Nirula *et al.* (1953), in the laterite areas, about twenty per cent of the seedlings in the nurseries are destroyed by termite attack.

Termites can cause heavy damage to the transplanted seedlings also. After transplantation, the plant is struggling for establishing itself in the soil, and any injury caused by the termites is very harmful to the plant. Richards (1917) observed that about twenty per cent of four year old palms in certain parts of Malaya were severely damaged by termites. Nirula (1955) recorded that unless precautionary measures were taken in the laterite tracts, a number of transplanted plants may be killed or their growth greatly retarded.

Older palms are attacked either through the crown or through the trunk. Corbett (1932) was of the opinion that *Coptotermes curvignathus* the common species of the termite damaging the coconut palm in Malaya, never entered through the base of the older palm. He observed workers of this species among the rootlets, but when these roots were cut away, the base of the palm was found to be entire. Fletcher (1919) observed *Odontotermes obesus* Ramb. damaging young coconut palms in Quilandy (Malabar) by making galleries on the trunk. Recently in Madagascar it was also recorded that the termites make colonies at the foot of the coconut palms and construct galleries up the stem. However, according to Nirula *et al.* (1953), damage to grown up palms in India is not so severe as to attract serious attention.

On account of the magnitude of the damage caused by the termites to coconuts, several control methods have been evolved and practised in different countries with varying degrees of success. Copeland (1931) recommended in the Philippines the complete removal of all the wood in the ground in advance of planting the seednuts. Similarly Corbett (1932) in Malaya considered that the only satisfactory measure for eradicating *Coptotermes curvignathus* on both rubber and coconut estates consisted in the destruction of all timber in which they could make their nests. He found mercuric chloride to give a palm temporary relief from termite attack, but its adoption meant frequent application of the chemical. He also suggested the pumping of sulphur and arsenic fumes into the runways. In India, the common practice has been to cover the germinating nut all round with a thick layer of sand instead of soil, and regular watering of the seedlings. Venkitasubban suggested the application of river sand and salt or the addition of *Melia indica* cake or castor cake while preparing the planting pits to ward off this pest.

BHC 10 per cent dust applied at the rate of 25·5 kg per acre to the soil of the coconut nursery before sowing of the seednuts keeps the seedlings free of termite attack.

Recently Nirula *et al.* (1953) tried some new insecticides against the workers of *Odontotermes obesus* Ramb. and found that parathion, penta-chloro-phenol, sodium penta-chloro-phenate and chlordane were effective.

HYMENOPTERA

OECOPHYLLA SMARAGDINA *F.*

The red ant, *Oecophylla smaragdina* F. occurs throughout the Indo-Australian region. The ant builds its nests in the folds of coconut leaves. Usually a tree is selected which is attacked by some scale insect, for the honey-like exudations secreted by them, on which these ants live to a large extent. If possible, the nest is built over leaves or stems infested by the scale insects. In other cases scale insects are introduced into the nests for the honey-dew.

Recently *Oecophylla* was observed in some parts of Vaikom taluk in Kottayam district (India), causing heavy damage to coconut palms by the colonisation of a Coccid on the inflorescence and leaves. Due to the injury caused by the Coccids, the nuts fall off and trees suffer considerably in yield.

These ants are also a source of considerable annoyance to the climbers who go up the palms for collection of nuts. On the other hand this ant is extensively insectivorous and does some good by destroying caterpillars, beetles, etc.

The radical control of this ant consists in destroying the nests by burning them with torches during night. Ayyar (1940) suggested spraying of contact insecticides on scale infested shoots visited by these ants, and banding of the tree trunks with tar or a sticky paste to prevent ants going up the trees. Recently chlordane, aldrin and parathion have been found sufficiently toxic to give effective control in sprays.

OTHER PESTS

THE RAT

Rats are a serious pest of coconuts. Dumbleton (1955) believes that rats destroy 50 per cent of the coconut crop on Fakarava and in some other islands of South Pacific 75 to 100 per cent of the crop is destroyed. Lassalle-Sere (1955) stated that it is no exaggeration to claim that the figures for copra exports in Polynesia could be increased and in some instances even doubled, if it were possible to prevent rats from attacking the nuts. It was also observed in the Laccadive Islands, that rats caused a loss of up to fifty per cent of coconut production.

Colonies of rats may be found in the crowns of the coconut palm feeding on nuts of all ages. In thickly planted coconut plantations, they easily jump from tree to tree. The species attacking coconuts in India is *Rattus rattus* Bl.

The bandicoot rat which is also known as Malabar rat or Pig rat causes serious damage to young coconut palms, particularly when they are from one to two years old. It eats the growing stem, resulting in the complete collapse of the young palms.

Control

Nirula (1954) has suggested the use of poisoned baits, fumigation of the rat burrows, trapping, erection of physical barriers, application of chemical repellents and encouragement of the natural enemies for the control of rats in coconut estates.

Poisoned baits

The more common poisons used are zinc phosphide, barium carbonate, strychnine, ' red squill ', ' antu ' and ' warfarin '. Warfarin is a comparatively new ' coumarine ' compound with anti-blood coagulating properties, which induces gradual internal haemorrhage. Warfarin kills rats after small quantities have been consumed over a period of several days. Because of slow death, the rats do not develop ' bait shyness '.

The poisoned bait should be placed in shallow uncovered trays in places frequented by rats. As the poisons generally used are dangerous to domestic animals and children, it is safer to use the baits at night in protected feeding stations or bait boxes as shown in the illustration (Fig. ***110***). Dumbleton (1955) has suggested the use of galvanised iron boxes which allow ingress to the rats, while protecting the poisoned bait against deterioration due to rain. These boxes can be fixed to the trunk of coconut palms. To dispel all suspicion on the part of rats, it is better to attract them to the selected places by placing unpoisoned attractive baits for about a week before putting the poisoned baits.

Poisonous gases

Rats living in burrows are destroyed by forcing into them poisonous gases such as sulphur dioxide, carbon disulphide, cyanogas, methyl bromide, etc.

Trapping

There are many different types of traps which are employed for capturing the rats. The more common of these are the snap back or guillotine traps (Fig. ***111***), the wire cage traps and the box traps (Fig. ***112***).

Protective barriers

To protect the coconut tree from the attack of the rats, metal bands or sloping bands of galvanised iron are fitted to prevent the creatures ascending up the coconut palms (Fig. ***113***). Lassalle-Sere (1955) reported that the experiments carried out in Tahiti had proved that metal bands fixed around the trunks of coconut palm provided adequate protection.

Chemical barriers consisting of distasteful and repulsive materials like coal tar etc., are employed but according to Nirula (1954), so far no persistent repellent has been found for application to green foliage.

Natural Enemies

All the common rodents are attacked by a number of natural enemies which help to check their increase. Nirula suggested that the owls, hawks, rat-snakes, cats and other animals that prey on rodents should be protected.

THE FLYING-FOX

The fruit-eating bat which is also popularly known as flying-fox, is a serious pest of coconut palms in several parts of the world. These bats appear to have a liking for most of the garden fruits, and when the fruits are scarce, they turn their attention to the nuts of the coconut palms. Copeland (1931) has reported the presence of these bats throughout the coconut areas in the Philippines, East Africa and West Indies. Simmonds (1924) has included them in the list of pests of coconut palms in the islands of the South Pacific. Recently Nirula *et al.* (1954) have described them as an important pest of coconuts on the West Coast of India.

The flying-fox, found damaging coconuts in India, is described as *Pteropus edwardsii* (Syn : *Pteropus medium* and *Pteropus vampyrus*) and belong to the family Pteropodidae of the order Chiroptera. According to Blandford (1891), it is present throughout India, Ceylon and Burma.

The flying-fox, *Pteropus edwardsii* (Fig. ***114***) is a massive flying creature with a wing span of about four feet. It is nocturnal in habits and during the day roosts on wide spreading high trees like banyan, *Ficus bengalensis*, tamarind, *Tamarindus indica* etc., in large colonies.

The feeding habits of this bat are quite peculiar and have been studied as far as coconuts are concerned by Nirula *et al.* Just after sunset, the bat alights on the crown of a palm and moves to the bunch by hanging on the leaf that subtends the bunch. The husk and the tender shell are bitten off and a wide hole, the diameter of which may sometimes be as much as 5 cm is made. The bat drinks the sweet water and afterwards feeds on the kernel. Generally the heavy bearing tall palms are selected and regularly visited by the bats.

A critical survey of some of the palms infested at the Central Coconut Research Station, Kayangulam (South India) indicated an average loss of 32·2 per cent in the affected palms. Fortunately, however, the number of such palms is restricted to only a few in a coconut garden.

It is difficult to control this pest. Copeland (1931) felt that something could be accomplished by shooting them in coconut gardens, but where the bats were numerous, it was considered necessary to break the roosts. Burning of sulphur in braziers under the roosting trees was not considered of much use as the bats would only shift to some other trees and probably might return to the same after a day or so. Gee has advised the killing of these bats by concussion produced by blasting at least a ten pound charge. Mehta (1956 — private communication) exploded two bombs each containing a kilogram of gelatinite around which one kilogram of leadshots were packed, 4 m below the roosting place. The concussion effect was found to be nil and some mammals which came down were found to be hit by lead pellets only. Mehta feels that flying-foxes can be best controlled by direct hit, and for that, a number of small bombs each containing 100 gm of explosive and one pound of lead pellets, should be exploded simultaneously in the roosts for achieving the best results.

THE ROBBER CRAB

The Robber crab, *Birgus latro* Hbst. (Fig. ***115***) is closely associated with coconuts growing on the coasts of the islands of the Indian and Pacific Oceans. Its distribution according to Child (1953), extends from Cocos Keeling Islands as far as the Purdy Islands in Bismarck Archipelago, and from the New Hebrides to Palmy Islands in the Pacific. However it is unknown in India, Ceylon, Africa and the American tropics.

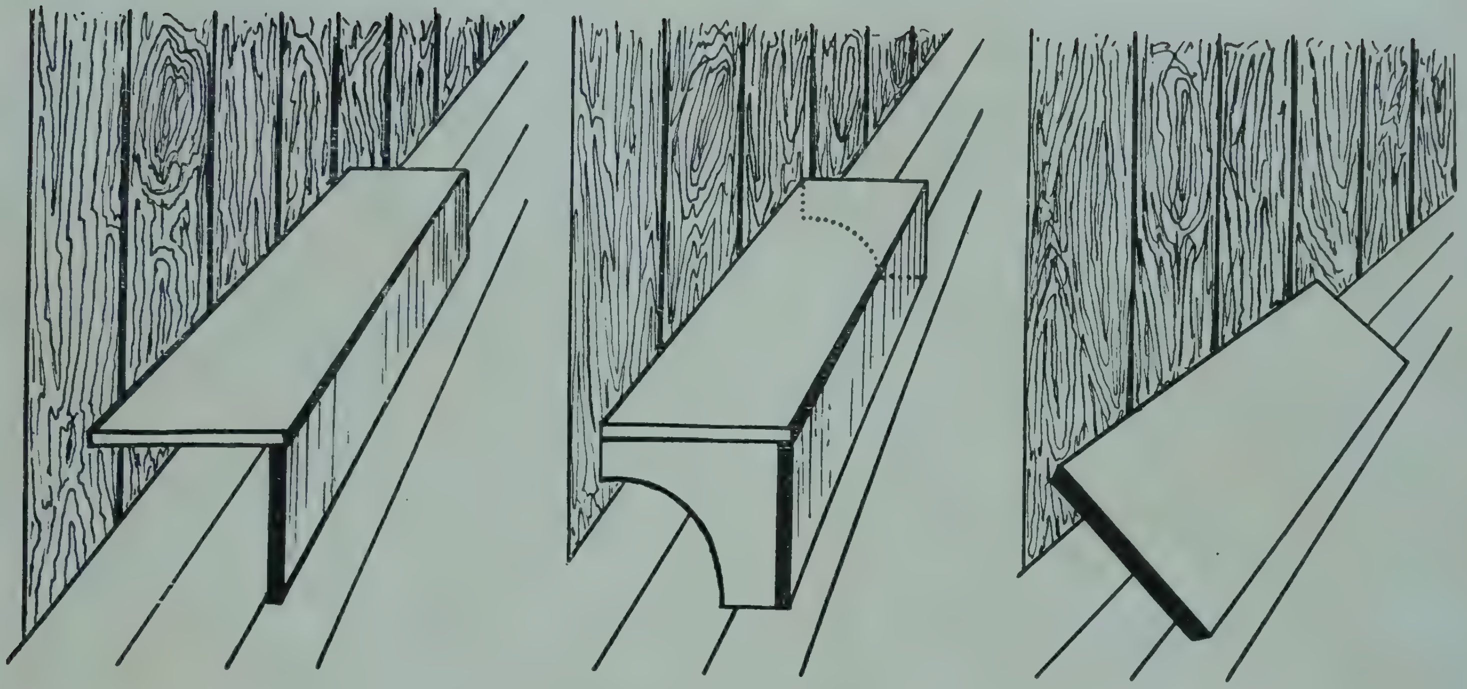


Fig. 110. Bait stations

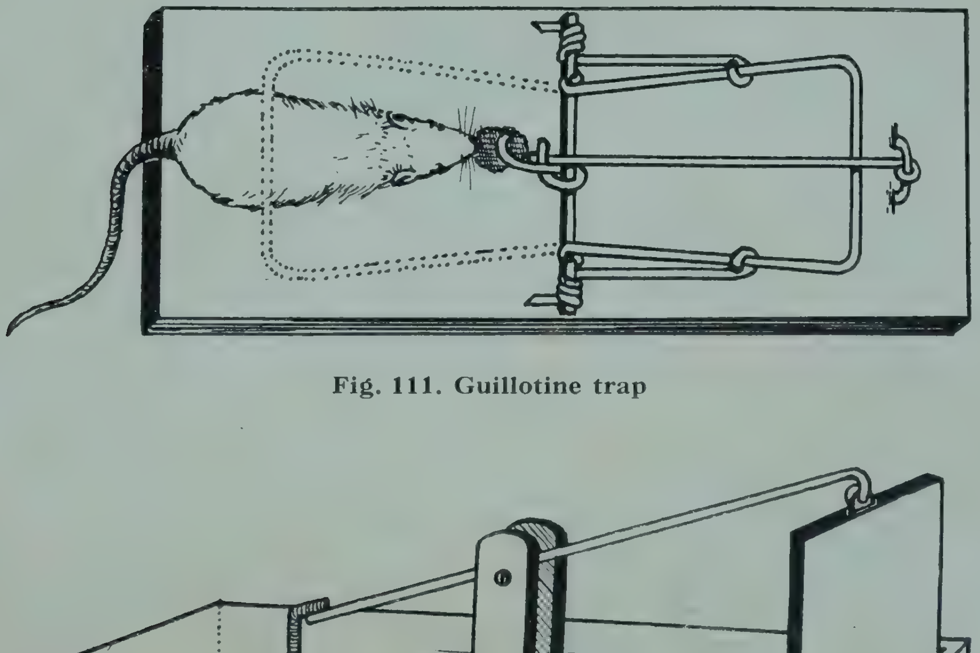


Fig. 111. Guillotine trap

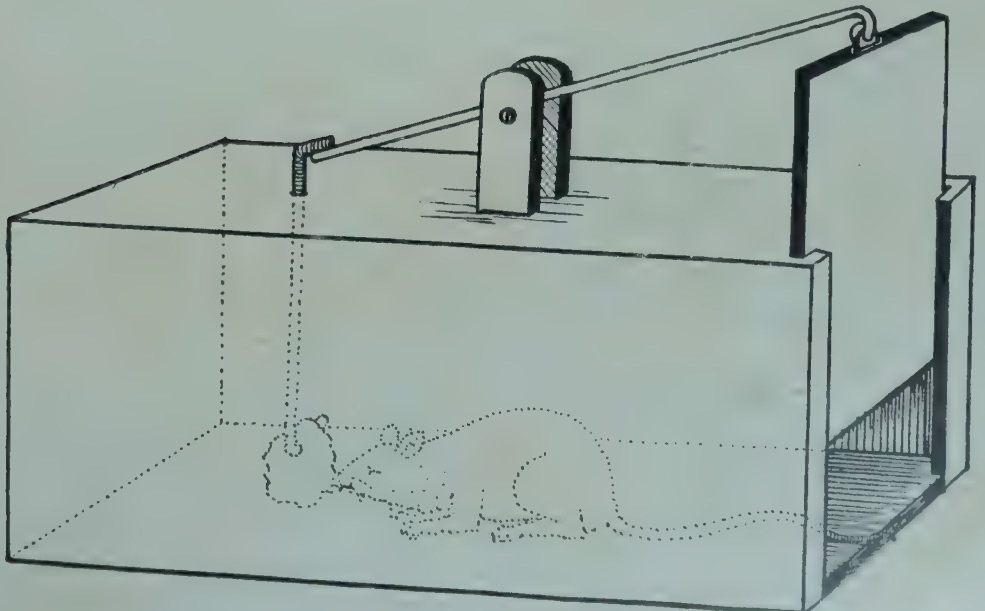


Fig. 112. Box trap

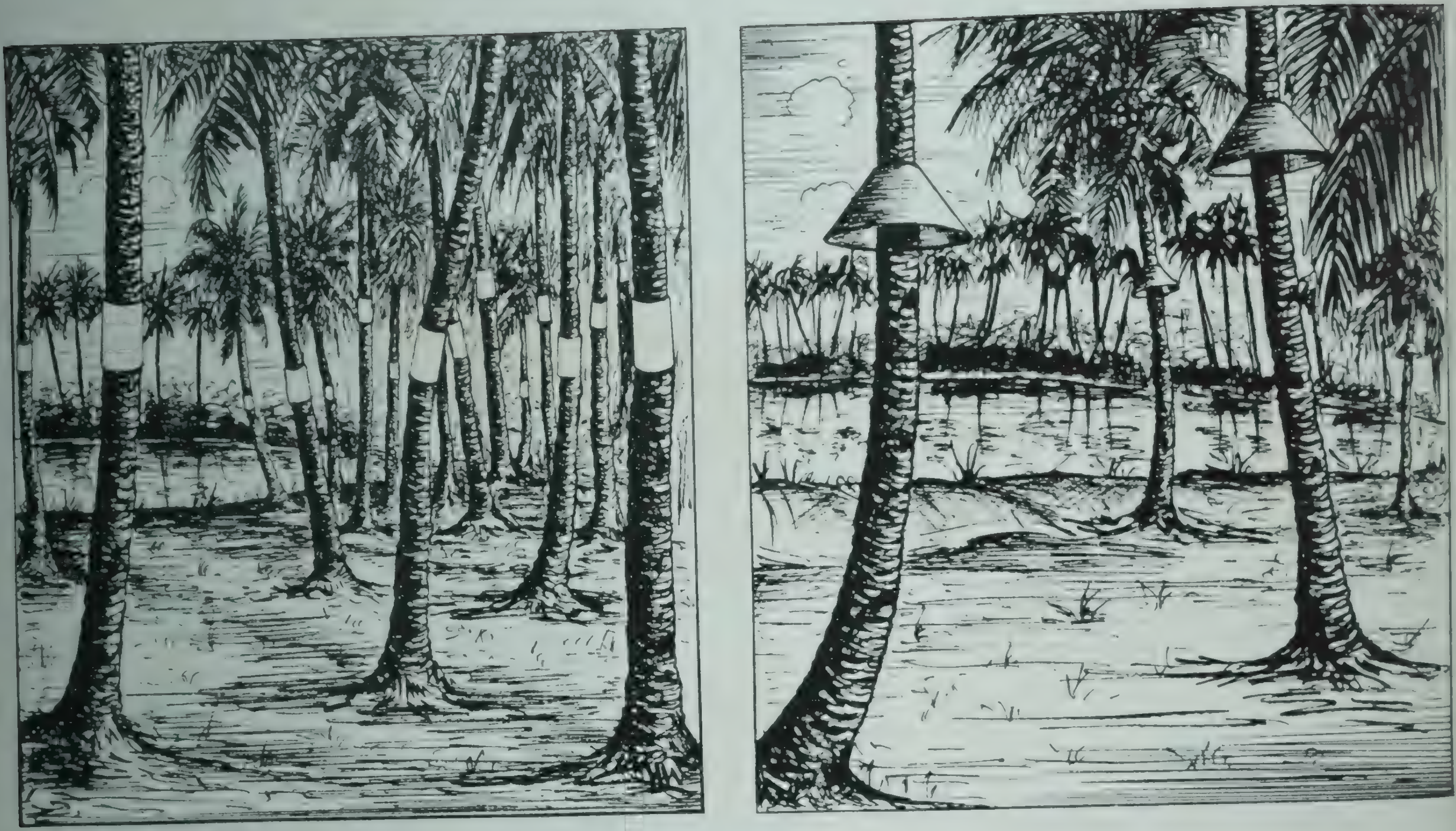


Fig. 113. Rat bands and slopes

Fig. 114. Flying fox

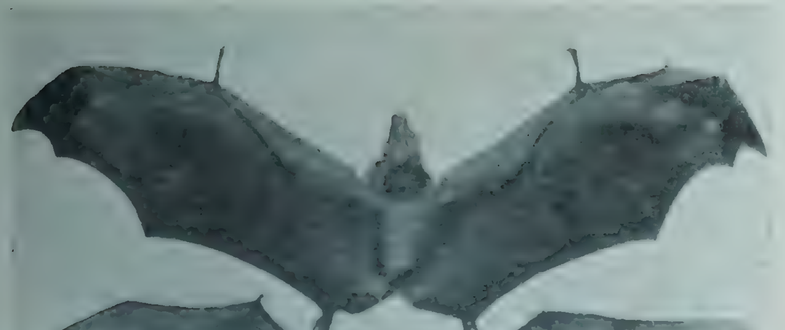
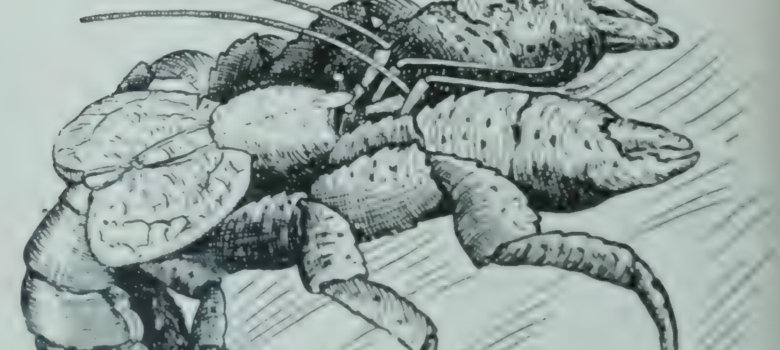


Fig. 115. Robber crab



The crab is a monstrous sized creature, sometimes more than a foot long. The first pair of legs terminate in very strong and heavy pincers, and the last pair possesses weaker and much narrower pincers. The crab begins by tearing the husk, fibre by fibre, and always from the anterior end. When this is completed, the crab commences hammering with its heavy claws on one of the eye-holes until an opening is made. Then it turns round its body, and by the aid of its posterior pincers extracts the soft kernel. Sometimes it breaks the shell by beating it on a stone. The crab not only destroys fallen nuts, but has been certainly known to climb trees and fell the nuts (Copeland, 1931). A crab can consume upto two nuts every day.

The crab itself is a highly prized article of food, and is therefore kept in check by human beings.

PESTS OF COPRA

Insects cause serious damage to copra in storage. Menon and Nirula (1956) estimated that the quantity of copra damaged in this manner every year in India was more than ten thousand tons. Apart from loss in tonnage, insect attack adversely affects the quality. In severe cases, the financial loss on this account may even exceed that arising from loss by weight.

Corbett *et al.* (1937) reported twenty-six insects associated with copra in Malaya, but found *Carpophilus dimidiatus* F., *Necrobia rufipes* de Geer. and *Ahasverus advena* Waltl., as the most prevalent ones. In India *Carpophilus dimidiatus* F., *Necrobia rufipes* de Geer., *Oryzaephilus surinamensis* L., *Tribolium castaneum* Hbst., *Trogoderma granaria* Evans, *Corcyra cephalonica* Staint., and *Ephestia cautella* Walk., are the more important insects found in copra godowns and mills.

(*a*) Carpophilus dimidiatus *F.*

It is the most common insect in copra godowns and mills in Malaya and other coconut producing countries. In India also it is commonly present in copra stores. The beetle is small, flat, broad, and about 3 mm in length and 1·5 mm in width. It can be readily distinguished from the other beetles by its shorter wing covers, which do not completely cover the abdomen. The beetle completes its life cycle in about five weeks.

(*b*) Necrobia rufipes *de Geer.*

Necrobia beetle has a world-wide distribution and is known as ' Ham Beetle ' in America and ' Copra Bug ' in the Pacific. It is generally metallic blue in colour but sometimes with a greenish lustre. Its length varies from 3·5 mm to 5·5 mm. The first five joints of the antennae are brown, the rest black, and the terminal three are expanded. It completes its life cycle in about 40 days.

(*c*) Ahasverus advena *Waltl.*

It is known as " Foreign Grain beetle," and is present throughout the world. It has been recorded feeding upon a variety of stored products. It is abundant in copra stores, but is practically mycetophagous. The adult beetle is very small, measuring about 2 mm in length and 0·75 mm in width, and is chestnut brown in colour. The life cycle of the beetle is completed in about thirty days.

(*d*) Oryzaephilus surinamensis *L.*

This Cucujid beetle is commonly known as " Saw Toothed Grain beetle," and it is a serious pest of stored grains, copra and other stored food products throughout the world. The adult beetle is small, flat, elongate, dark brown, about 3 mm in length and 0·75 mm in width. The pro-thorax has three longitudinal ridges with two depressed areas and its lateral margins are each armed with six prominent tooth-like projections. The beetle breeds throughout the year in the moulds and crevices of degenerated copra, and completes its life cycle in about thirty days.

(*e*) Tribolium castaneum *Hbst.*

It is commonly known as " Red Flour beetle ", and is primarily a pest of cereal products like wheat flour, ' *suji* ' and ' *maida* ', but causes damage to quite a number of other stored products including copra. Passmore has noted that this was one of the three beetles most prevalent in copra arriving in U.K. The beetle is small, flat, elongated, reddish brown, about 3·5 mm in length and 1·25 mm in width. The first seven joints of the antennae show a gradual increase in size and the last three are thickened into a club. In India, its life cycle varies from six to twelve weeks.

(*f*) Trogoderma granaria *Evans*

This pest is known as ' Khapra ' in the towns and villages of India, and its principal food is wheat. The adults are harmless, and only the grubs are destructive. The beetle is about 3·5 mm in length and 1 mm in width, and has a characteristic oval shape. The head is disproportionately small and is concealed from above by the pronotum. The life cycle in humid places is completed in about two months.

(*g*) Corcyra cephalonica *Staint.*

This pest is commonly known as the Rice Moth and is a serious pest of stored paddy, rice, cereals, copra and other stored food products. The head and thorax of the moth are brownish in colour. The fore-wings are brown with a pinkish tinge, speckled with darker scales running longitudinally. The hind wings are shiny and silver grey. The wing expanse is about 25 mm.

(*h*) Ephestia cautella *Walk.*

This is frequently referred to as the ' Almond ' or the ' Fig Moth ' and is one of the most important insects infesting dried fruits, cocoa, spices, cashewnut, copra and groundnut. The moth is about 6 mm in length with a wing expanse of 15 mm. Its colour varies with food and environments, but mostly the fore-wings are greyish-brown, somewhat mottled with a distinctly darker coloured transverse band. The average life cycle on mouldy copra is six weeks.

Nirula and Menon (1956) reported that some of the insects were attracted to coconut meat as soon as it commenced to deteriorate. Others get access to the copra in stores, where they might remain always hidden in the crevices of building, debris, etc. They were also attracted from the already infested copra in adjacent storage places. Bags used for transport and storage also carry a number of these insects.

Preventive and remedial measures

Corbett *et al.* (1937) and Nirula and Menon (1956) reiterated that the prevalence of insects in copra stores was intimately connected with the quality of mouldy or deteriorated copra. The reduction of insects associated with copra must therefore commence right from the time of its preparation. After splitting, the coconut meat should immediately be subjected to a constant and uniform temperature, so that its moisture content could be reduced to below 6 per cent in the minimum possible time, thereby inhibiting the growth of the fungal moulds.

The next important point suggested was to ensure that the bags used for the transport and storage of copra were free from insects, for which purpose they suggested the use of fresh bags every time or heat sterilization or fumigation of old bags. Another possibility suggested was the impregnation of the bags with insecticides like DDT, DDD, etc.

Certain preventive measures in copra mills and stores would be useful. These include the maintenance of strict hygiene, involving the immediate removal of spillage, systematic turning over of stock, regular removal of webbing and cleaning out of all hidden spaces, which form breeding places for the insects. Another important consideration is that the store should be kept dry and should not leak during rains so that the copra is kept at such a low moisture content that insects, mites, moulds and micro-organisms cannot flourish.

The safest and most effective way of disinfecting warehouses, stores and godowns, suggested was to spray the structure with DDT or BHC. General fumigation is an emergency measure, and the infestation returns to the original level in three to four months.

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CHAPTER XV

TAPPING

The term ' tapping ' collectively denotes the various processes of stimulating the different toddy yielding palms to exude juice from a selected part. In the date palm (*Phoenix dactylifera*) and Bajur palm (*Corypha elata*), the entire growing point is cut off, exposing the tender cabbage. The top of the naked stem is scooped to form a shallow depression where the juice gets collected. In palms like the wild date palm (*Phoenix sylvestris*) and the African palmyra, a lateral portion of the young stem is tapped. In the sugar palm (*Arenga saccharifera*), *Arenga pinnata*, Wights sago palm (*Arenga wightii*), etc., it is the stalk of the inflorescence that generally exudes sap. In water coconut (*Nipa fruticans*), Indian sago palm (*Caryota urens*), coconut palm (*Cocos nucifera*) and palmyra palm (*Borassus flabellifer*), it is the inflorescence in its particular stage of growth that is stimulated to give the juice. Fermentation of the juice results in a liquor which is a popular and intoxicating drink and is commonly known as ' toddy '.

In India, the coconut (*Cocos nucifera*), palmyra palm (*Borassus flabellifer*), Indian sago palm (*Caryota urens*) and the wild date (*Phoenix sylvestris*) are the most common palms tapped. The sago and the wild date palms are exclusively used in the toddy industry. In coconut, toddy comes in importance only next to copra and husk, which are the most important products. The coconut toddy industry has its due importance in certain parts of India.

In the coconut, the toddy is obtained from the inflorescence before the flowers fully develop. The fresh toddy on evaporation of water by boiling yields an abundance of unrefined sugar known as jaggery. According to Pandre Blance (Blatter, 1926), its immoderate use by the Filipinos caused great harm resulting in sleepiness, loss of appetite, premature old age, extraordinary obesity and diseases resembling dropsy and scurvy. Some of those that are addicted to it lose their intellectual faculties. From the fermented liquid a kind of rum called ' arrack ' is distilled. If the fermented toddy is allowed to undergo acetic fermentation, good vinegar is produced.

Season and stage of tapping

Since the coconut usually produces inflorescence regularly in the successive leaf axils, there is no definite season for tapping the coconut. Tapping is carried out throughout the year either on the same trees or on different trees. However, a palm yields larger quantities of juice during certain months of the year. On the West Coast of India, formerly there were two periods of tapping : (1) the dry weather tapping usually from November to March ; and (2) the wet weather tapping from April to October. Dry weather tapping is mostly confined to low-lying lands where the trees do not suffer due to want of soil moisture during droughty weather. Generally the most vigorous trees located in comparatively more favourable environments are selected for tapping. In India, particularly on the West Coast, tapping is done for a short period of six months on one set of trees. On vigorous trees it is continued for even to two years. In countries like Ceylon, Philippines, and some of the Pacific Islands, trees are continuously tapped for a good number of years. In these countries, entire gardens are set apart and equipped for the collection of toddy. It has been observed that some trees have been toddy yielders throughout their life.

Judging the correct stage when the spadix is suitable for tapping is a matter of experience. As a rule, a spadix is considered ready to be operated upon when the previous one has just burst or is about to do so. The development of the female flowers inside the spathe causes a swelling at the base of the spathe, and the appearance of this swelling is an indication of the approximate stage for tapping. However, depending on the skill of the tapper, a slightly more mature spadix in less vigorous trees, and less immature spadix in more vigorous trees are selected. If the spadix is fully mature, it becomes uncontrollable, as the spathe bursts open while training it for tapping. Even if this could be successfully trained, the exudation of juice is bound to be much less.

Methods of tapping

Though the methods of tapping differ in details in different places, the essential principles remain the same throughout. On the West Coast of India, the inflorescence suitable for tapping is first ' trained '. Training consists of gentle uniform beating all over the surface of the spathe twice a day, in the morning and in the evening. Then, three-fourths of the lower length of the spathe is wound round with a strong string, commonly the fibrous cord of the coconut leaf petiole. In some cases, where there is the fear of the spathe bursting, tying precedes beating. After a week's beating, about 7 cm to 10 cm of the tip of the spathe is cut off. In some places this naked surface is pounded with the handle of the tapping knife. This process is continued in the morning and evening for about a week according to necessity. By this time, the surface appears moist due to the oozing of juice. The early and proper flow of juice depends mainly upon the skill of the tapper. Special care is taken not to reduce the flower buds inside the spathe to a pulp in which case the spadix becomes useless. In some places, a $2\frac{1}{2}$ cm to 7 cm wide ring of the spathe from the tip is removed carefully without in any way injuring the spikes. This fresh portion is tied up with tender leaflets. The tapper pares a thin slice off the end of the spathe both morning and evening or once a day. The naked surface is often protected with a cap made of leaf stipule. When the above operations are continued for a few days, the juice begins to trickle. When the flow of juice starts, the paring of the tip is done thrice a day. A receptacle, such as an earthern pot specially made for the purpose, is just hung from the spadix so as to enable the juice oozing from the cut surface to collect in it. The interval from the commencement of tapping to the dripping of juice depends on the skill of the tapper, the method of tapping adopted, the seasonal conditions prevailing and the nature of the tree. This period varies from about ten to twenty-five days. According to Marsden and Skilton (1931), in Malaya, the flow of juice commences in about three weeks after the first operation on the spadix.

In the Laccadives and in the Philippines, when the juice begins to drip, the spathe is removed carefully exposing the inflorescence which is tied together and operated upon. Such complete stripping of the spadix is done to prevent rotting of the tender tissues by contact with the toddy. In some other countries this purpose is served by making a longitudinal slit in the spathe at the base of the spadix with the tapping knife.

Training the inflorescence is a long process in the Philippines and Pacific Islands. The unopened inflorescences are selected and are bent downwards slowly and gently, this operation being repeated several times a day for about one or two weeks. By doing this, the entire inflorescence droops and the cut surface practically faces downwards. This avoids the toddy entering into the inflorescence ; further, it enables the use of cylindrical receptacles like bamboo or bottles to collect the juice. In India, the use of specially designed mud pots as receptacles and making a slit in the lower part of the spathe save the tedious process involved in the training of the spadix. The appliances used for tapping in India are shown in Fig. ***116***.

Toddy is usually collected both in the morning and evening. If the trees are tapped for sweet juice, it is collected invariably in the morning. However, in some places collection is done twice a day.

In the tapping operations on a spadix, after the flow of juice has commenced, paring a thin slice off the spadix afresh may be done twice or thrice a day according to requirements. The cut surface is covered with a thin layer of fine clay. In other places, however, slicing is followed by washing and rubbing the cut with the paste of the leaves of " Achil " tree (*Aporosa lindleyana*). This prevents the rapid healing (drying) of the surface. Any mucilaginous leaf as that of *Hibiscus* also can be used for this purpose. Ingenious tappers use flower stalk of other bunches to clog the interspaces between spikes and flowers when they are too wide. In some countries, after the juice begins to drip, the beating or pounding is stopped. In some places, particularly in Ceylon, as soon as the toddy is removed, the tapper taps the spadix with his mallet and then pares the tip. It is interesting to note that in the Philippines " the tip of the inflorescence, including the tip of the spathe and the branches of the inflorescence, may or may not be bound with string ; the wounded end of the inflorescence may or may not be bruised to stimulate the flow of sap, but usually the cutting alone is relied upon to produce the flow " (Brown, 1951).

Yield of juice

There is considerable variation in the yield of juice from day to day, season to season, spadix to spadix and tree to tree. Sap always flows more readily in the night than in the day time. During cloudy weather, the flow of sap increases, but as the dry season continues, the flow gradually falls off again. The flow of sap varies with the state of the spathe which is being tapped. In the beginning when the tip of the spathe is being worked upon, the flow is small, but this gradually increases and reaches its maximum when that part of the spathe where the female flower buds are situated is reached, (Sampson, 1923). Eaton (1916) records that in moist localities in Ceylon, with one tapping a day, the yield of juice per tree varies from 600 cc to 1,200 cc and with two tappings 1,200 cc to 4,738 cc. He mentions that the total yield per spadix ranges from 19·9 litres to 42·1 litres. Marsden and Skilton (1931) state that in Malaya, the average daily yield of toddy per palm in the year is 2·1 litres, varying from 1·5 in December to 4·8 litres in July. The maximum yield of juice was obtained about five weeks after the commencement of the flow, i.e., in about eight weeks after the commencement of tapping. Jack and Sands (1922, 1929) from their observations in Malaya, record that the yield of juice from a dwarf palm ranges from 0·28 litre to 3·4 litres per day, the average being 0·85 litre. Even though the tall palms yield more juice than the dwarf palms, the tapping of dwarf palms is advantageous since the dwarf palm yields juice earlier on account of early flowering and their juice is sweeter and is easily collected as the palm is short. However, recent observations made by Nathanael (1956) have shown that under the climatic conditions prevailing in Ceylon, the '*nana*' or dwarf variety of the coconut palm may not prove economical for tapping purposes.

In a tapping experiment conducted at the Central Coconut Research Station, Kasaragod (Patel, 1938) the average daily yield of juice per tree was observed to be about 1,590 cc. The following are the salient observations made by him.

(*i*) Daily variations

The graphs indicate the daily variations in the production of sap for trees on which tapping was commenced in two different seasons, viz., December and April. It would be seen that the maximum quantity of juice was obtained in each case, in the third month of tapping. (Figs. ***117*** and ***118***).

(*ii*) Seasonal variations

The seasonal variations in the yield of juice represented in the graphs (Figs. ***117*** and ***118***) show that the trees on which tapping was commenced in April gave the minimum quantity of juice in September to December after which the yield of juice increased. During the north-east monsoon, the yield of juice was very small since, during this period, the spathes invariably burst open before the proper stage for tapping was reached.

Variation in the yield of juice among the spadices

Table (51) shows the variation in the production of the juice, in two sets of trees on which tapping was commenced in the months of November and April respectively. The mean average for the November group is about 18,000 cc per spadix with the coefficient of variability at 50 and for the April group about 15,500 cc with the coefficient of variability at 55.

Table 51.—Variation in the production of juice per spadix

Serial Number of spathe	Average yield of juice per spathe in hundreds of cc. Commencement of tapping in	
	November (*a*)	April (*b*)
1	109·3	66·9
2	171·1	271·4
3	226·0	282·2
4	75·7	216·8
5	188·7	202·6
6	141·7	32·1
7	95·0	182·4

Table 51.—Variation in the production of juice per spadix.—(*Contd*).

Serial Number of spathe	Average yield of juice per spathe in hundreds of cc. Commencement of tapping in	
	November (*a*)	April (*b*)
8	170·1	26·1
9	97·0	118·4
10	15·1	28·0
11	115·0	221·8
12	235·4	219·4
13	188·6	151·6
14	264·5	140·0
15	293·5	..
16	201·0	..
17	414·2	..
18	236·1	..
Total	3,238·0	2,168·7
Mean production ..	179·0	154·9
Coefficient of variation	50·3	55·2

(*a*) Average from five trees.
(*b*) Average from four trees.

The results summarised in the following table are from a larger number of trees than those considered in the previous table. It will be seen that the period during which the spadix yields juice varies from spadix to spadix.

Table 52.—Yield of juice

Season	Number of trees	Number of spadices	Mean yield per spadix cc.	Coefficient of variability		Mean Number of days for which juice was obtained	Coefficient of variability
				Spadix	Tree		
April	7	7	18,890	43·4	58·0	32·8	34·5
April	4	14	15,490	55·2	12·6	27·7	40·0
November	5	18	17,990	50·0	55·5	28·0	18·3
November	13	8	12,810	31·4	65·1	27·3	16·7

The mean interval, in days, between the commencement of tapping and the commencement of the yield of the juice was 22 days and 15·2 days, respectively, for April and November, the respective coefficients of variability being 18·1 and 13·5. There is less variation in all the trees first tapped in November; but from the points of early flow, larger yield of juice and longer duration of the yield, the April tappings are better.

Duration of tapping

The period for which the trees can be tapped economically, is an important consideration. A frequency distribution drawn with the daily yield of toddy for 357 days, gave a curve which was dissymmetrical. This can arise either through a small number of observations or through the observations spread

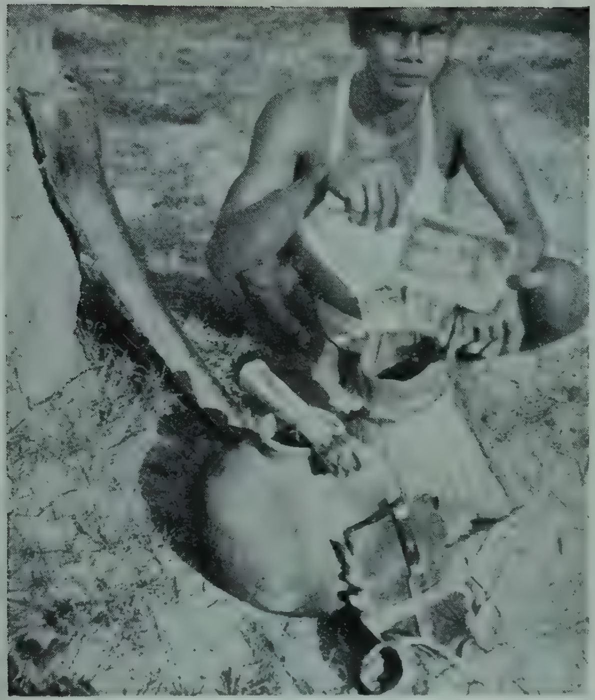


Fig. 116. Tapping appliances

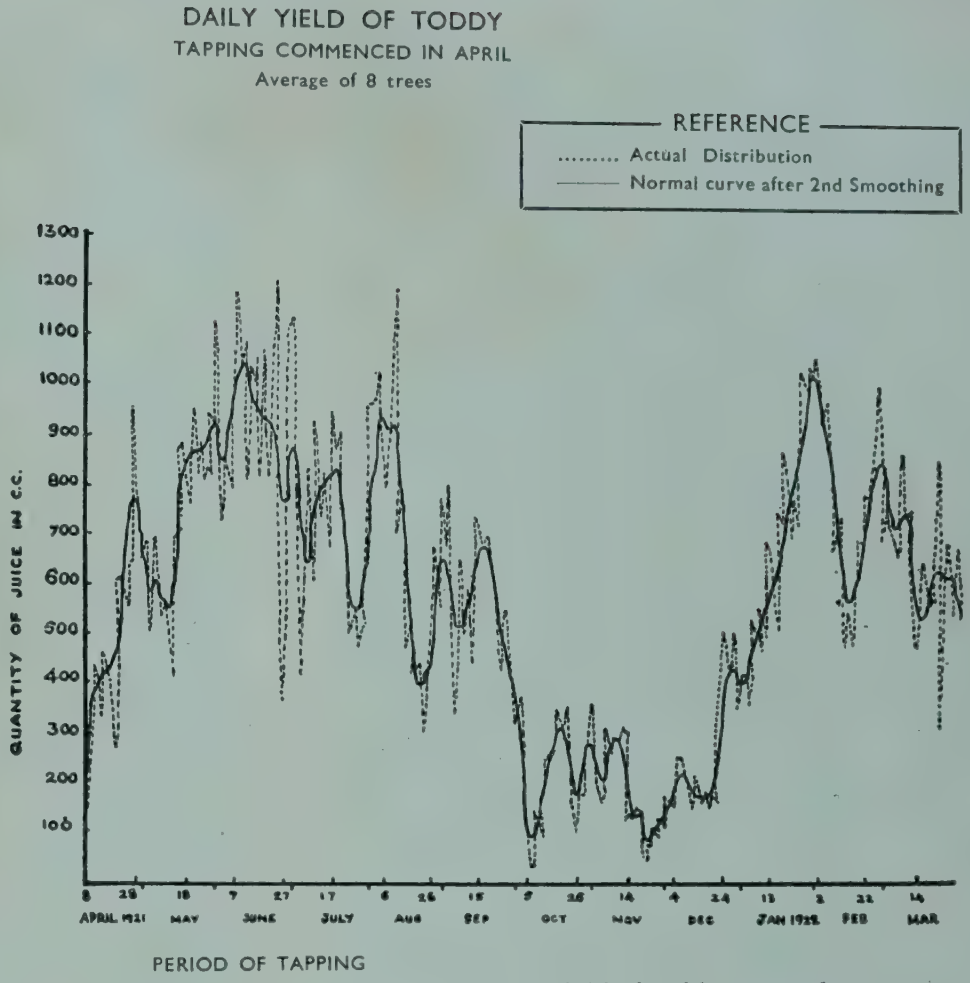


Fig. 117. Daily yield of toddy — graph
(After Patel, 1938)

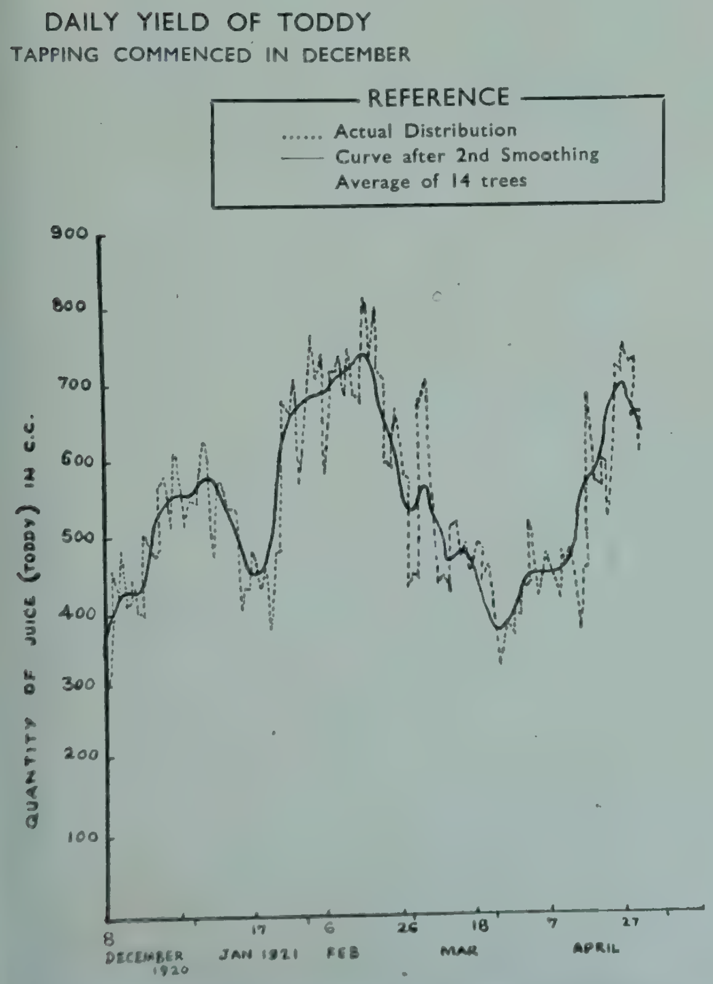


Fig. 118. Daily yield of toddy — graph
(After Patel, 1938)

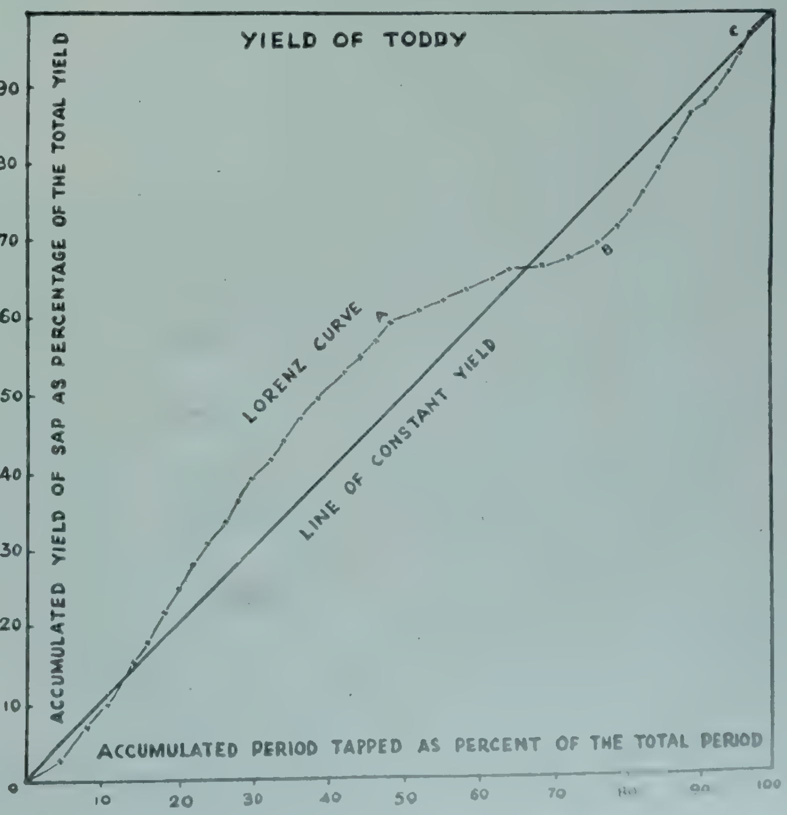


Fig. 119. Yield of toddy — graph
(After Patel, 1938)

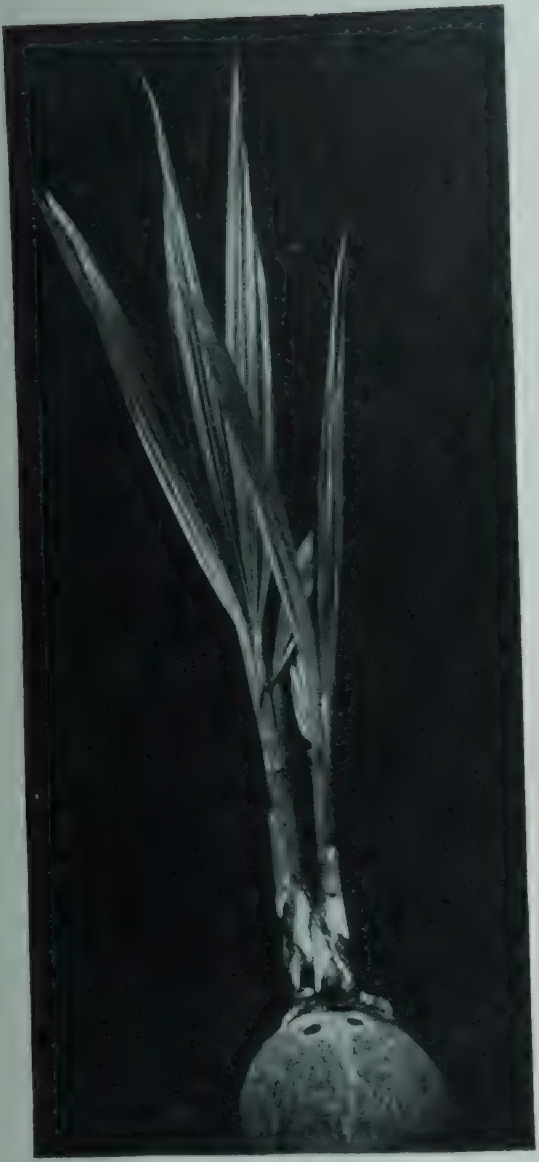


Fig. 120. Poly-embryony

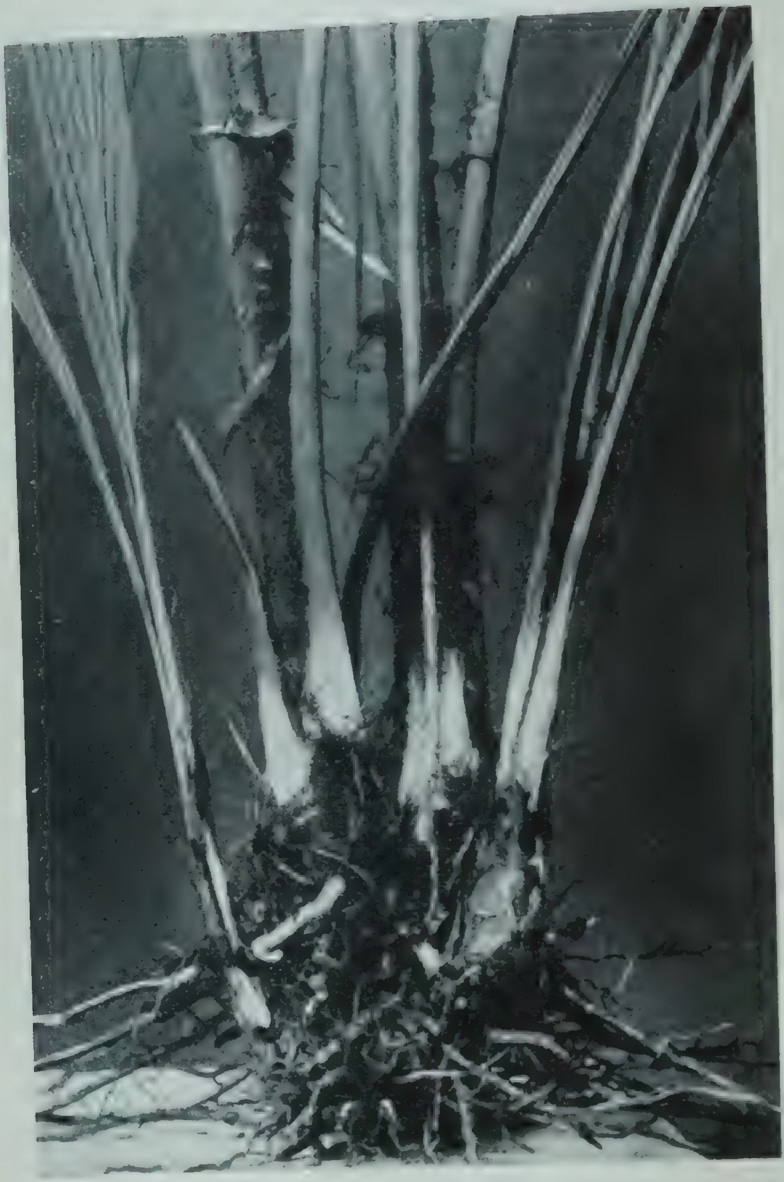


Fig. 121. Suckering seedling

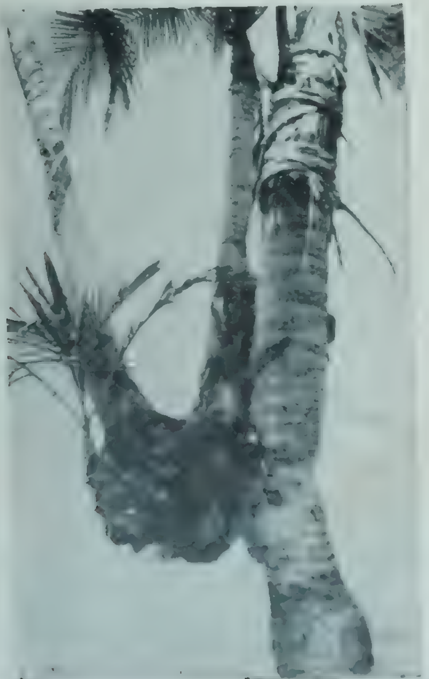


Fig. 122. Branched palm

over too long a period. The former is not likely since 358 readings cannot be considered too small. When the distribution was plotted for the yield of toddy during 176 days, it gave a more or less normal curve with a low measure of skewness. It is, therefore, apparent that a normal distribution of the yield can be expected if the trees are tapped for about six months only. If tapping were to be continued further, there would be large variations in the yield with frequent low yields. The continuous tapping of trees, therefore, for more than six months at a time may not be profitable.

Here Lorenz curve (Fig. ***119***) is more useful than the frequency distribution, since it clearly indicates the independent variates lying in the given limits of the dependent variates and vice versa. The OA portion of the curve represents the portion of the highest yield, and AB the lowest. OA represents 60 per cent of the juice and 48 per cent of the period while AB represents 10 per cent of the juice and 28 per cent of the period and BC 30 per cent of the sap and 24 per cent of the period. The tapping, is therefore, most economical in about 50 per cent of the period, i.e., during the first six months. Thus the data are in conformity with the local belief that it is better and economical in the long run to tap for six months in a year, say from April to September, particularly in places where the trees are subject to drought. In Malaya, however, according to Marsden and Skilton, the palms are given rest for about four months after tapping them for about eighteen months.

Relationship between the yield of sap and other characters of the trees

The correlations between the total yield of juice per tree and the characters tabulated below were worked out for two groups of trees A and B. The group A consisted of 53 trees, tapping on which was commenced in December and the yield of juice continued from January to May. The group B consisted of 24 trees tapping on which was commenced in March and yield of juice continued from April to July. The average yield of nuts per annum was calculated from the yields during 1920 and 1921 the two years prior to tapping. The average production of female flowers was similarly obtained and the number of leaves on the trees was that present in 1922. The coefficients of correlation are tabulated below.

Table 53

Total correlations between	Group A			Group B		
	r	z	Normal* variate	r	z	Normal* variate
1. Toddy and number of nuts	0·67±0·07	0·8107	5·7323	0·756±0·059	0·9867	4·5190
2. Toddy and number of female flowers ..	0·417±0·083	0·4441	3·1397	0·534±0·097	0·6242	2·8588
3. Toddy and number of leaves	0·253±0·09	0·2586	1·8283	....	..	..
4. Toddy and number of spadices tapped ..	—0·280±0·09	0·2877	2·0340	....	..	..
5. Number of nuts and number of female flowers	0·683±0·068	0·8347	5·9013	0·644±0·08	0·6460	2·9587

* P. for 0·01 = 2·5758

The coefficients of correlations for the number of nuts and female flowers are significant. Since almost all the variates used in finding out the above relationships are inter-dependent, the coefficient of correlation obtained for each combination is not the measure of the absolute relationship between the two variates. In order to elucidate the relationship between the variates, the partial correlations for the following absolute relationships were worked out:—

Partial correlations

	Group A	*Group B*
Between yield of toddy and nuts for constant female flower production	0·543 ± 0·069	0·644 ± 0·08
Between yield of juice and number of female flowers for constant yield of nut	0·070	0·230 ± 0·13

There is positive and significant correlation between the yield of toddy and the yield of nuts even when the number of female flowers is kept constant; but the total correlation obtained between the yield of juice and the number of female flowers is only spurious. Even though the total correlation between the yield of toddy and the number of spadices is not significant, the negative value of *r* requires some explanation. Generally the flow of the juice from the spadix is less in the initial stages of tapping, and, in most cases, it completely stops or decreases, when the juice from the succeeding spadix begins to flow.

The effect of tapping on the yield

Since tapping was discontinued in August 1922, the yield of 1924 and 1925 only are taken as post-tapping yields. The yields for 1920 to 1921 are taken as pre-tapping yields, and the mean increase in the yield has been calculated for the different groups of trees according to the initial yields. The results are tabulated in the table below:—

Table 54.—Effect of tapping on yield

Block	Group	Treatment	Number of trees	Average yield per tree per year 1920 and 1921 pre-tapping	Average yield 1924 and 1925 post-tapping	Mean (increase) deviation with P.E. The difference between the mean deviations for tapped and untapped trees	The difference between the mean deviations for tapped and untapped trees
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VIII	Above 100 nuts	Tapped per year	11	117·6	122·5	5·0 ± 5·0	23·3
I	do.	Untapped	14	177·2	98·9	−18·3 ± 7·30	..
VIII	71–100 nuts	Tapped	35	83·9	81·6	−2·3 ± 1·60	−1·5
	do.	Untapped	33	82·7	81·9	−0·8 ± 1·66	..
I	51–70 nuts	Tapped	29	59·6	64·8	5·2 ± 1·80	3·7
	do.	Untapped	33	60·3	61·8	1·5 ± 1·66	..
VIII	31–50 nuts	Tapped	36	40·5	50·3	9·8 ± 1·33	3·5
I	do.	Untapped	30	41·7	48·0	6·3 ± 1·33	..
VIII	Below 30 nuts	Tapped	5	19·8	39·9	20·1 ± 2·93	16·3*
I	do.	Untapped	5	21·6	25·4	3·8 ± 4·07	..

* The increase in yield consequent on tapping is only significant for this group.

The mean increase in the yield, after tapping (vide column 7) is significant in the case of trees the average yields of which were below 70 nuts per annum, per tree; but a similar increase, excepting for the group below 30 nuts, has taken place for untapped trees in Block I. It may be concluded that there are indications, that tapping increases the yield of poor bearers only.

In the following table, the group below 30 nuts per annum, is taken for further analysis, to see how far the effect of tapping, if any, lasts. The yields for 1920 and 1921—pre-tapping periods are compared with biennial yields from 1924 and 1925 to 1932 and 1933 — the post-tapping period. The increase in the yield of the tapped trees in block VIII is compared with the increase in the yield of the untapped trees in Block I. At the end of 1927, the differences between the means of increases in the yields for tapped and untapped trees become not significant, indicating that the effect of tapping has lasted upto 1928, that is, for four years. This is in conformity with the general practice adopted by some tappers. They tap the poor yielders for a season or two and then allow them to produce fruits. When the yields commence to fall, tapping is again resumed.

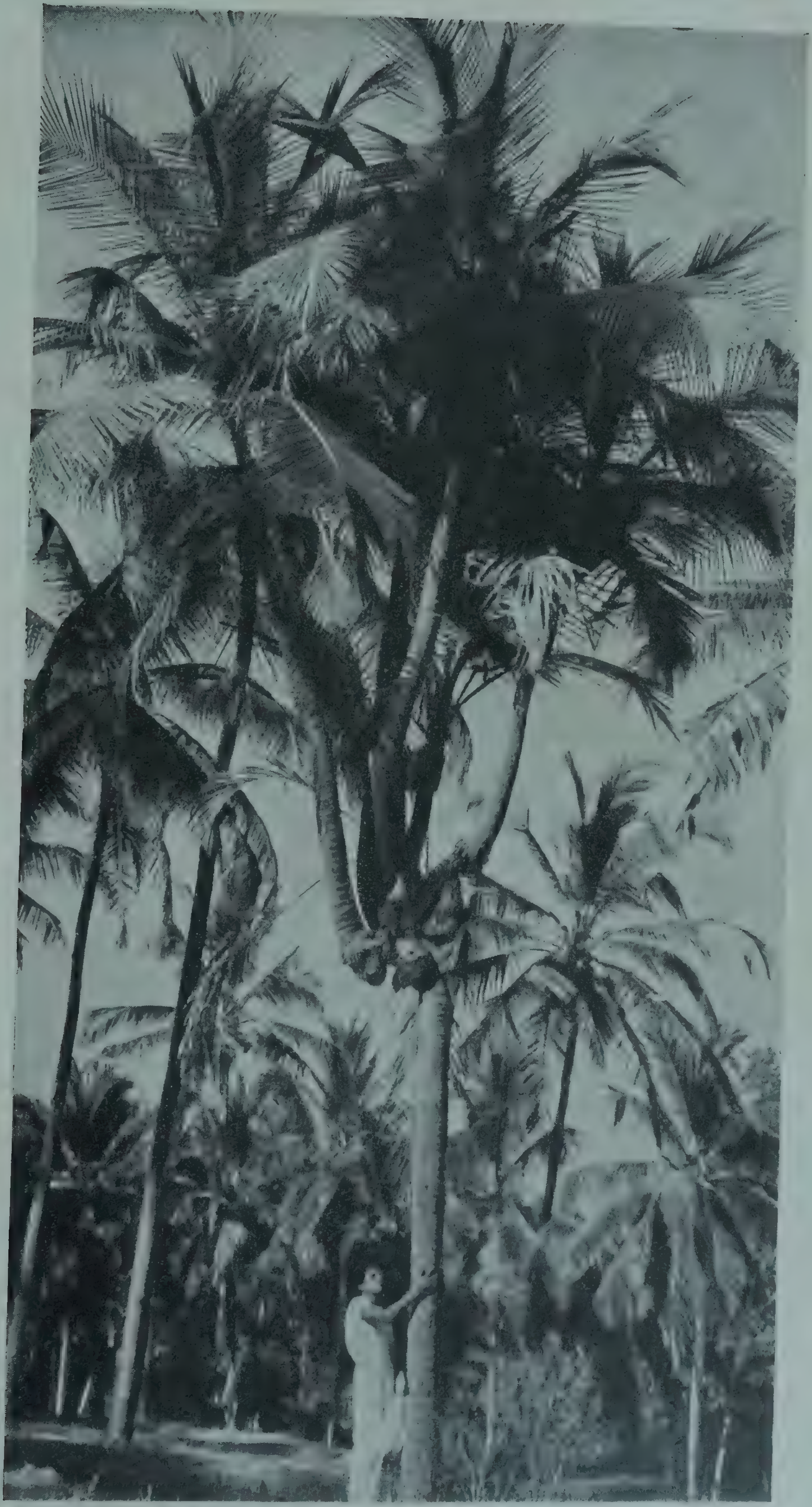
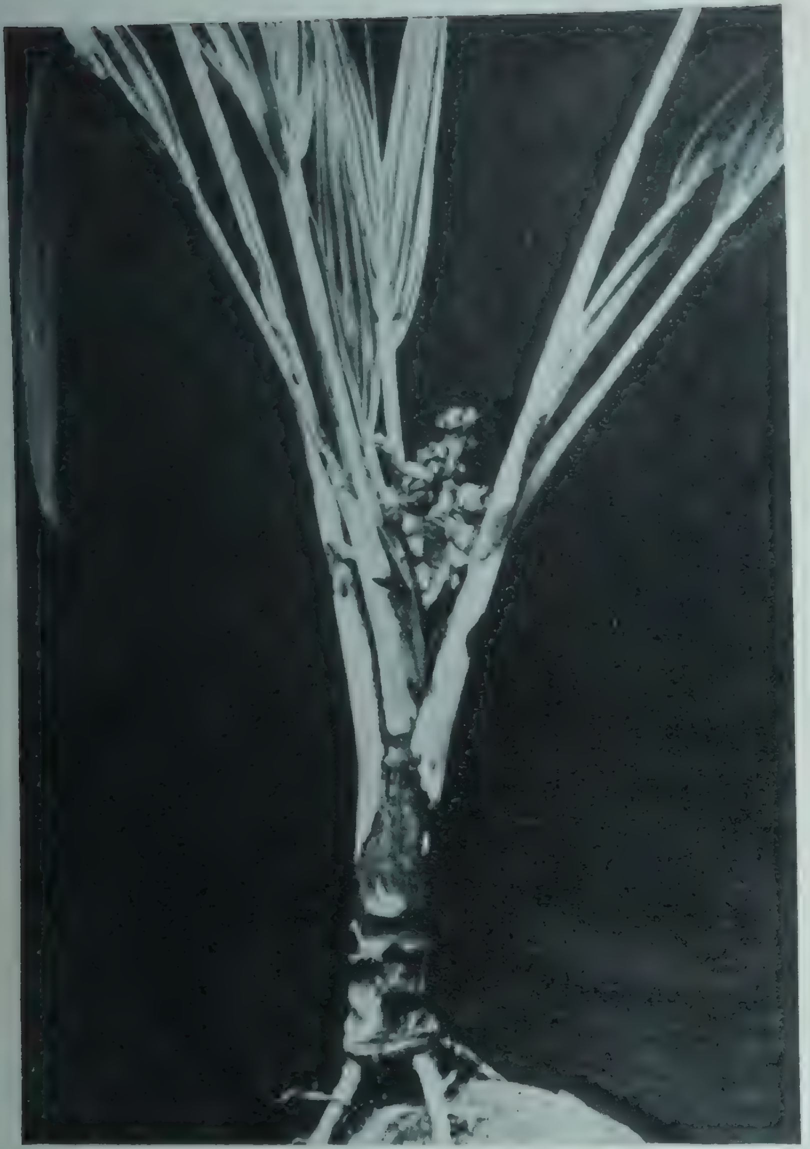


Fig. 123. A branching coconut tree growing near Calicut (Kerala)



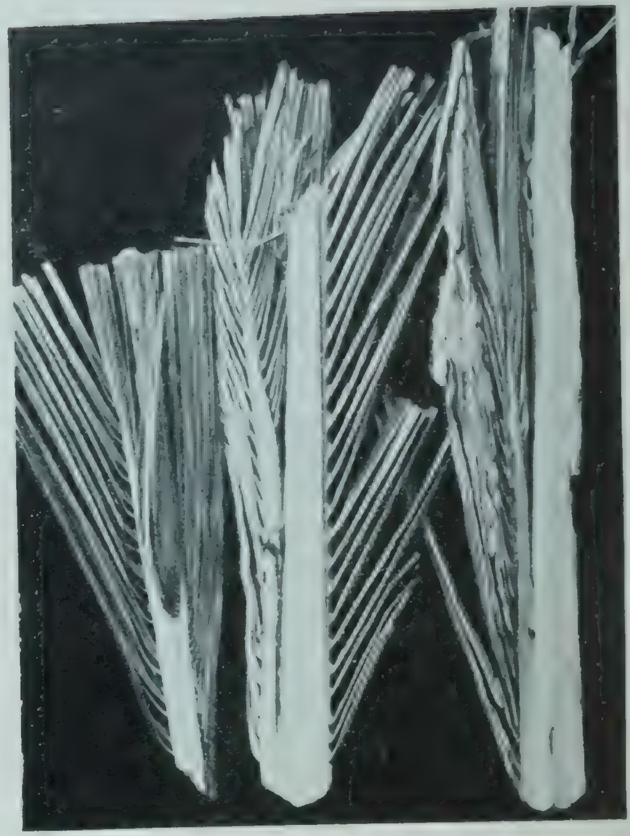


Fig. 125. Forked leaves

Fig. 124. A Midget coconut palm

Fig. 126. Twin leaves

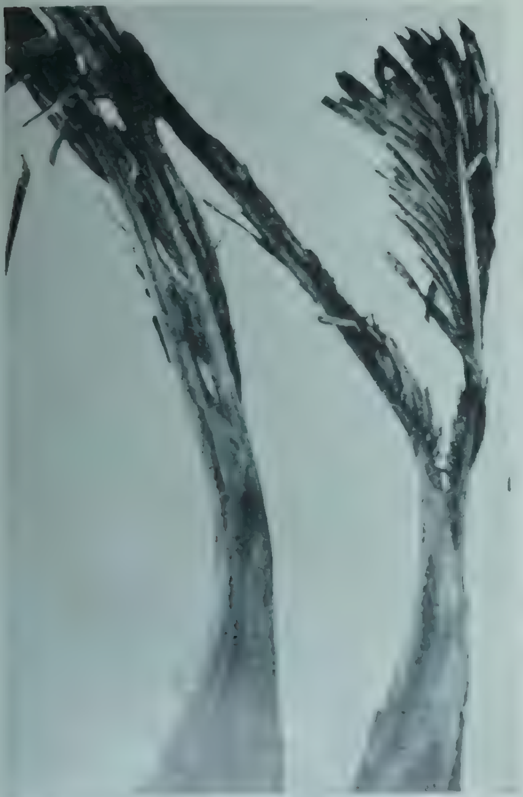


Fig. 127. Male bunch of a sex dimorphic palm

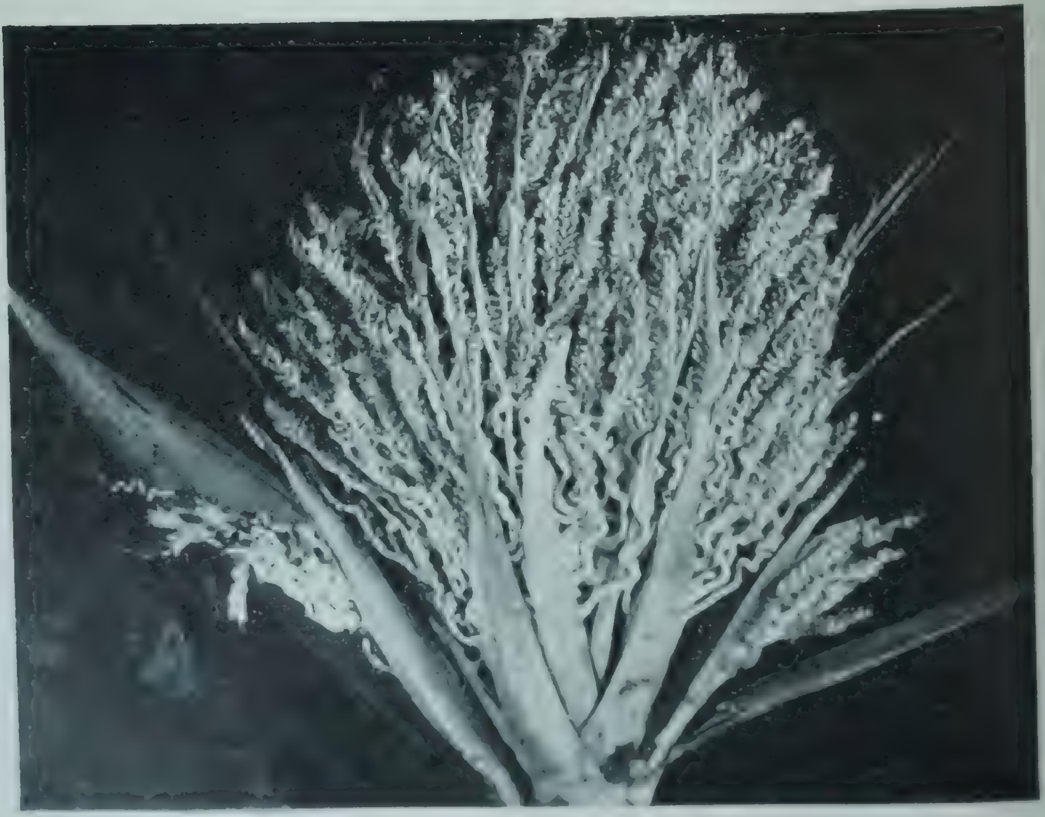


Table 55.—Group below 30 nuts per tree, per year

Years of Comparison	Increased yields per tree per year for		Difference	't' calculated	Value of P	Remarks
	Block VIII tapped	Block I untapped				
1920 and 1921 with 1924 and 1925	20·1	3·8	16·3	1·937	0·05	Significant
1920 and 1921 with 1926 and 1927	30·5	10·8	19·7	1·970	0·05	,,
1920 and 1921 with 1928 and 1929	43·3	28·3	15·0	1·010	Between 0·3 and 0·4	Not significant
1920 and 1921 with 1930 and 1931	47·9	28·2	19·7	1·544	"0·1 and 0·4	,,
1920 and 1921 with 1932 and 1933	40·2	17·5	22·7	1·858	"0·05 and 0·2	Significant

The experiments of Jack and Dennet (1925) in Malaya show that the yield of copra and oil per nut is less for the tapped trees than for the untapped trees, but the physical constants of oil obtained from untapped and tapped trees show no significant differences. Their results are tabulated below.

Table 56.—Percentage and physical constants of oil

Treatments	Weight of meat in gm	Moisture per cent	Percentage of oil	Weight of copra in gm per nut	Weight of oil per nut in gm
Untapped	511	51·5	66·5	263·2	175·0
Tapped	490	49·5	63·2	242·5	153·3
Difference	21	2·0	3·3	20·7	21·7

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CHAPTER XVI

ABNORMALITIES

Although the coconut palms are remarkably uniform in their morphological features, a number of abnormalities in respect of the tree, flower and fruit have been met with. These have been periodically reported by workers. Some of the striking instances are described in the following pages.

Abnormalities in the vegetative parts

Poly-embryony.

A nut on germination may give rise to one and sometimes to two or three shoots, each through a separate ' eye '. But in rare cases, more than one shoot is seen emerging through a single eye. This phenomenon is called poly-embryony. Each ' eye ' represents a carpel which is one-ovuled. Normally, one carpel with a developed ovule is capable of producing only a single shoot. Furtado (1926-29) describes a few cases of poly-embryony. He carefully examined a nut which produced three distinct shoots emerging through the ' soft eye '. The two other ' eyes ' were closed and were as hard as those in an ordinary nut where the two carpels are abortive. On breaking the nut open, it was observed that each shoot had its origin, in a separate embryo, each having a haustorium of its own. There was only one cavity in the endosperm into which these three haustoria developed, and there were neither hard nor leathery dissepiments in it. The kernel inside also showed no signs of any special connection with the ' closed eye ' as it showed with the ' soft eye '. Costerus and Smith (1923) described a coconut which had given rise to three sprouts, which on careful opening did not show any dissepiment whatsoever. Only one germinating plant forcing its way through one of the black spots was to be seen, but the stem of this plant showed a separation into three. Smith is convinced that the coconut with three cohering stems is after all a case of poly-embryony with the difference that the embryos have coalesced to a certain extent and are entirely free as in other cases of poly-embryony. Instances of poly-embryony have been described in detail by Davis *et al.* (1953). Fig. ***120*** shows the development of two almost similar shoots emerging through the single ' soft eye '. The two ' hard ' or ' blind eyes ' are clearly seen in the figure. Each seedling had an independent haustorium or ' apple ' within the nut and there was no dissepiment present to separate the embryos.

Suckering.

Branching in palms restricted to the underground portion of the stem (bole) or when it happens at the ground level is termed ' suckering '. These branches usually emanate from the nodes that are buried in the soil. An interesting case of suckering in coconut has been noted by Patel (1938) at Kasaragod which has produced as many as forty suckers. These suckers, though weak, looked quite normal and resembled the ordinary young palms. One of these suckers on replanting, established itself and commenced flowering, but did not produce suckers. A similar case has been noted by Shortt (1885) who observed six shoots in a seedling. A large number of instances of suckering in coconut palms has been described by Davis (1955), Fig. ***121***.

Suckering in coconut is an economically interesting phenomenon and this has been detailed by Davis (1956). Holttum (1955) also indicated the utility of this phenomenon in the breeding of the economic palms, namely coconut and African oil palms. He suggested that if one could stimulate the suppressed basal buds to develop, vegetative propagation in palms would be possible. This fact has also been indicated by Furtado (1922).

Branching.

Branching is a rare phenomenon in the coconut palm. It is also of considerable importance as it provides a means for securing increased yields with less planting space. Morris (1892) studied the phenomenon of forked and branched palms. Branching in coconut may take place at all stages of growth and from the various regions of the stem. Branched coconut palms have been described by various writers like Burkill (1923-25), Furtado (1923-25), Quisumbing (1926-27), Ridley (1907), Jacob (1935) and Davis (1947, 1950, 1956 *a*). A few such instances are illustrated in Figs. ***122*** and ***123***.

Branching in coconut has been attributed to the following causes. When the growing point of a young palm is injured, there is a tendency for the bole to throw out adventitious buds because of the meristematic activity of the ground tissues of the bole. Sometimes, the flower branches vernate into vegetative branches which are termed " bulbils ". Instances are on record where some of these " bulbil-shoots " develop into real branches on the death of the terminal shoot. Branching is also induced consequent on the injury of the terminal bud by rhinoceros beetle, lightning and by diseases, fire, storm, etc. Instances of fasciation and dichotomy have been recorded by Jacob (1935) and Davis (1950 *a*) respectively. According to some, branched palms are usually unproductive, but a large number of instances have been recorded where branched palms bear normally.

Abnormal leaves.

According to the phyllode theory of monocots, the monocot leaf is said to be the expanded petiole of an ordinary leaf, the lamina portion having been lost in the course of evolution (Arber, 1918). The lamina portion of a palm leaf, that is the ' fan ' or ' feather-limb ' according to her, (Arber 1922-23) is not the morphological lamina, but only a modification of the distal region of the true petiole. Leaflets are formed in a coconut leaf as a result of the primary division of the original petiole.

Abnormalities in leaves are less common than in other parts of the palm. However, instances of abnormalities are sometimes met with and these have been described in detail by Davis (1956 *b*). The more common among these are instances of forked leaves (Fig. ***125***), twin leaves (Fig. ***126***), fused leaves, multi-leaf, etc. These variations are brought about by various causes. Patel has also recorded instances of certain abnormalities on trees advanced in age where leaflets are fused and do not separate as in ordinary palms. This, according to him is brought about by a genetic factor or factors.

Albinism.

In coconut nurseries, a few albino seedlings with complete white or yellowish leaves are sometimes noticed. The albinos, according to Patel, are less than 0·1 per cent of the total number of seedlings. These do not respond to manurial treatments.

Patel is of opinion that albinism is most probably due to certain genetic factors brought together by cross pollination. Furtado (1926-29), on the other hand believed that albinism in coconut seedlings is due to ' some internal factor and chlorosis due to lack of ferruginous products in the endosperm '. Such seedlings have been observed to be devoid of chloroplasts and generally die after producing 4 to 6 leaves.

Abnormalities in sex expression

Male coconut.

Normally, the coconut palm is monoecious, bearing male and female flowers in the same inflorescence. Occasionally, however, it has been observed to express unisexual condition which is possibly a stage in evolution.

John and Narayana (1942) have described a few male coconut palms which produced only male flowers. These were otherwise quite similar to the ordinary tall variety of coconut. The male inflorescence is more robust and has numerous spikes and very many male flowers. These flowers are larger in size than those of the ordinary palm. Male coconut palms have also been met with in many other places in India and these have been examined by Davis *et al.* (1955). They observed that the spadices of these trees showed branched spikes and often produced secondary spadices. Invariably such an inflorescence has numerous spathes or highly developed bracts. The inflorescence of a male tree has a greater number of male flowers per bunch than in the ordinary palm. John and Narayana (1942) recorded 14,000 flowers per inflorescence in this variety.

These palms although of no economic value, may prove useful for the tapping of toddy.

Female coconut.

Instances of female coconut palms (Fig. ***124***), which flowered within a year of transplanting have been described by Davis and Menon (1953), Davis (1955) and Rao and Subbiah (1954). Such palms have been designated " Midget palms " by Davis and Menon. These palms bearing the terminal inflorescence died soon after producing the first inflorescence. The inflorescence was conspicuous for the absence of the spathe. However, two bracts developing just below the corymbose inflorescence took the place of the spathe. They bore only female flowers, and these ranged up to eleven in an inflorescence. The gynoecium of the flowers is very interesting as it comprises only of free carpels. One of its

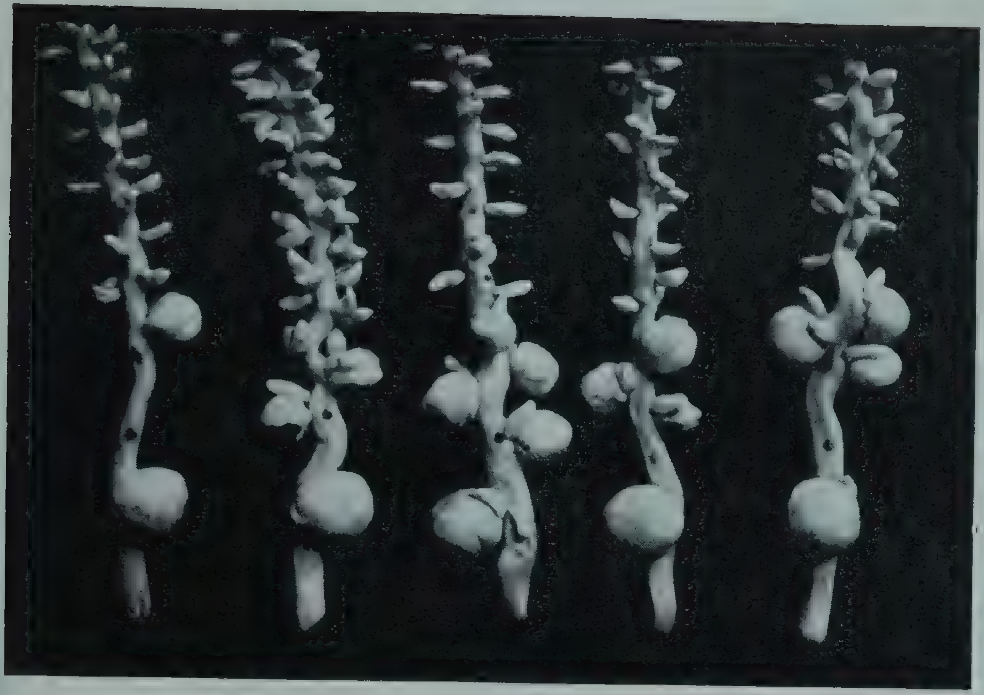


Fig. 128. Spikes with hermaphrodite flowers

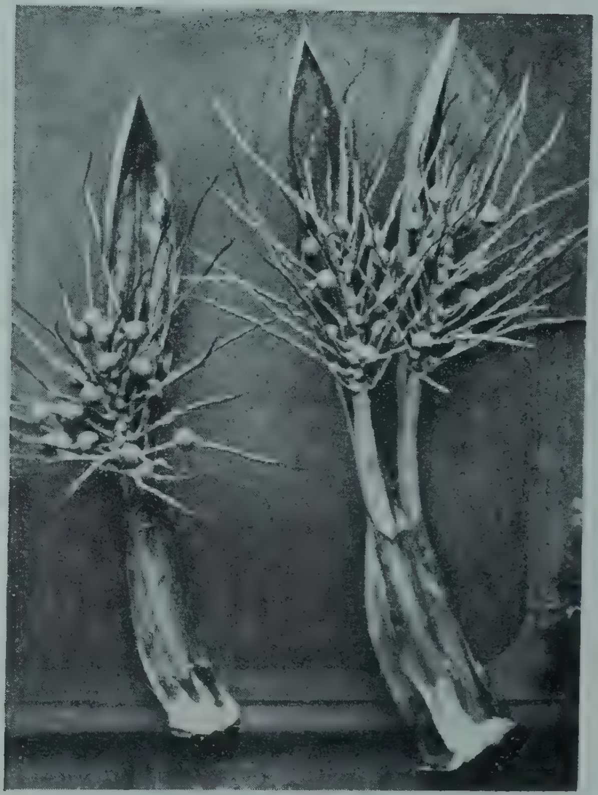
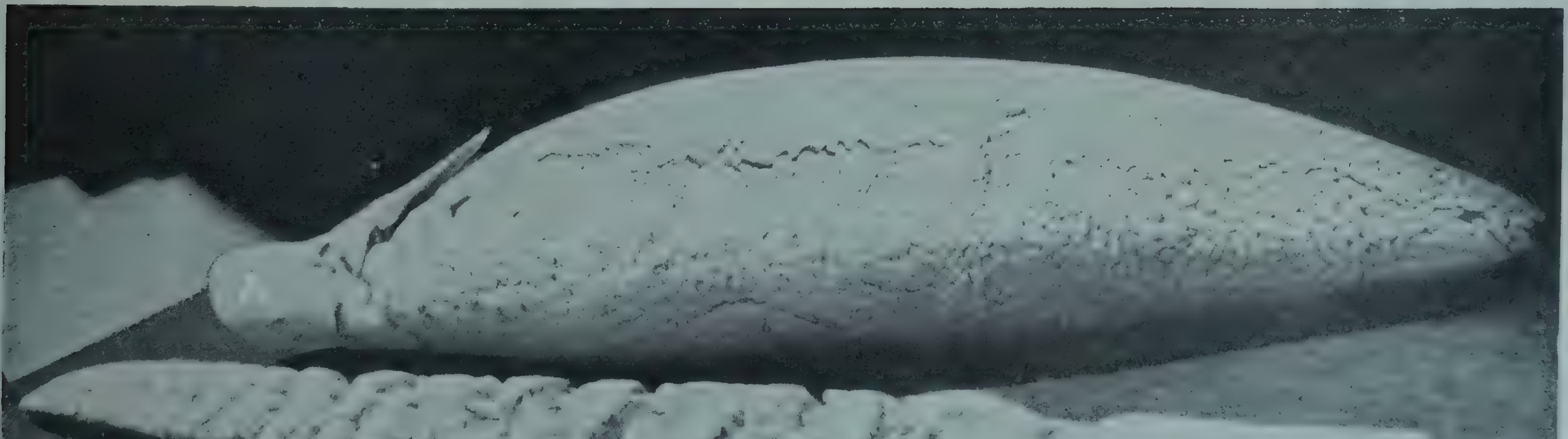


Fig. 129. Double spadix

Fig. 130. A. Inflorescence of a male tree
B. Spikeless inflorescence



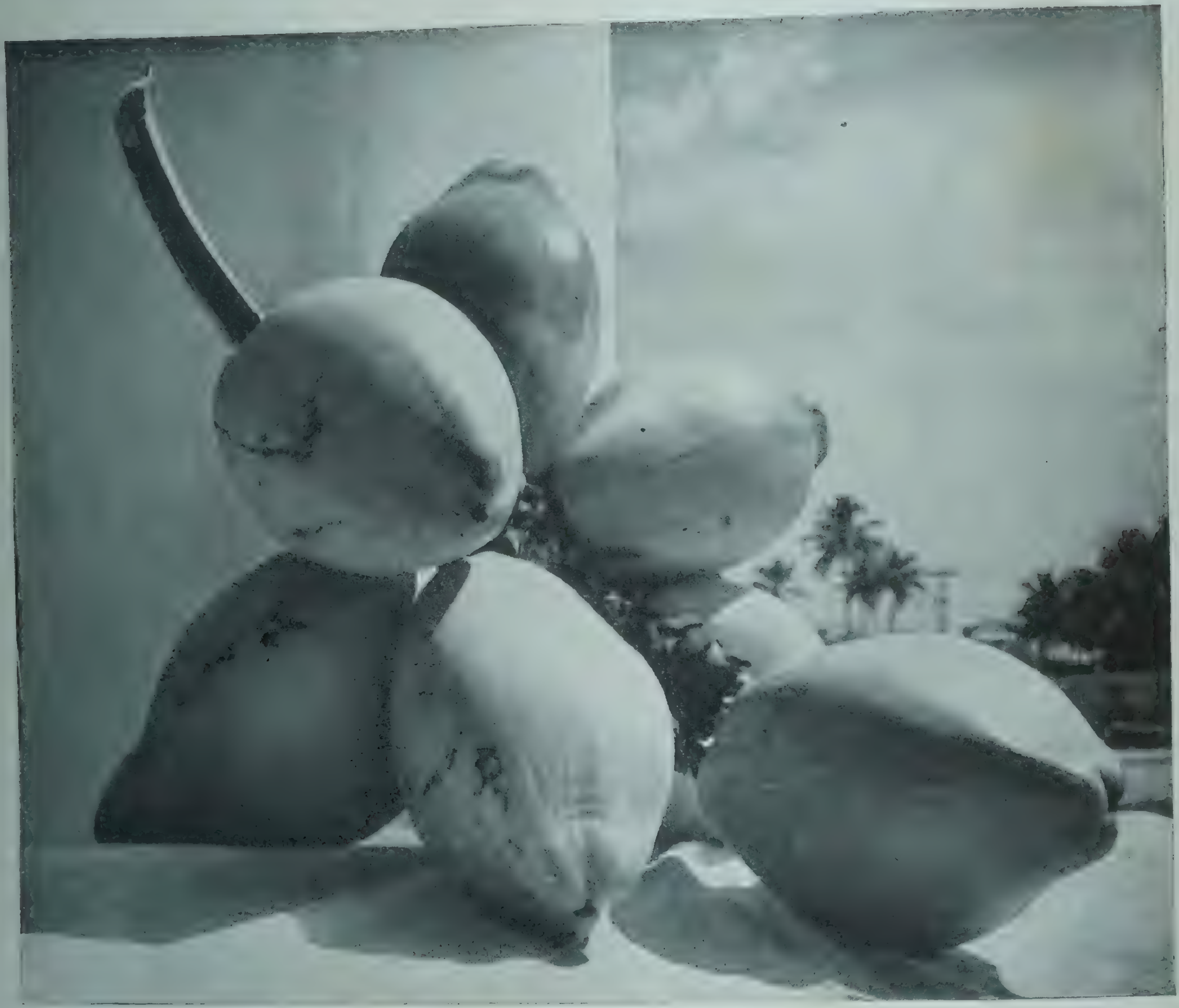


Fig. 131. Unbranched bunch

flowers had only two carpels. Gadd (1924) describes some abnormal female flowers of coconut, where the three carpels were fused only at the base, being free to a greater or lesser extent at the apex. Another factor which is common to most of these peculiar seedlings, except the one reported by Rao and Subbiah is that they are progenies of the dwarf variety.

Sex dimorphism.

An interesting palm has been recorded by Davis *et al.* (1955) wherein the inflorescences produced were pure males during certain months of the year, while during other months they bore both male and female flowers. The male inflorescences of this tree (Fig. ***127***) were more robust than the androgynous ones produced at other seasons. Peculiarities of this palm included (1) the more robust bunch when it bore only male flowers ; (2) production of larger number of secondary spadices, spikes and spathes ; (3) production of a markedly larger number of male flowers per bunch and (4) the presence of a leafy structure at the tip of the spathe.

Hermaphroditism.

Coconut is normally monoecious, bearing male and female flowers separately in the same inflorescence. Gopala Rao (1948) reported a stray instance of a bisexual flower in the coconut. Instances of trees which bear hermaphrodite flowers along with male and female flowers have also been noticed. These have been described by Davis *et al.* (1954). Fig. ***128*** shows the relative position and size of the hermaphrodite flowers in a spike. Each spike has one normal female flower at the bottom and numerous male flowers towards the top. In between the female and male flowers are the hermaphrodite ones located and they are bigger than the males and smaller than the females. Some of these hermaphrodite flowers develop into nuts. These nuts are smaller in size than the normal ones.

Abnormalities in the inflorescence

Normally the coconut produces a single spadix (enclosing a simply-branched inflorescence) in the axil of every leaf. An instance has been met with where two spadices have been observed in one axil. There are also certain trees which constantly produce unbranched inflorescences. There is another instance where the basal half of the inflorescence was observed unbranched while the apical half was branched as in the normal inflorescence. In yet another instance, the tree has been observed to produce inflorescences having secondary branches. Instances have also been noted where the spadix produced two spathes instead of one as in the normal spadix.

Double spadix.

Davis (1957 *a*) has recorded a double inflorescence from a tree at Nagercoil, S. India. Each spadix has an independent and fully developed spathe. However, the outer spathe is common to both the spadices. Each spadix bears numerous robust female flowers (Fig. ***129***).

Bispatheate Coconut.

The palm reported by Davis and Menon (1952) has two fully developed spathes in every inflorescence. Normally, an inflorescence has four bracts and the third bract or the second from the innermost one develops into the spathe and the others remain underdeveloped. But in the present case, the innermost bract also develops to the size of the original spathe and these two spathes completely cover the spadix till its emergence.

Unbranched inflorescence.

A number of trees having unbranched spadices have been recorded at various places. Patel (1938) mentions the occurrence of such interesting trees at Coimbatore, Madras city and Trichur. Jacob (1941) studied in detail the morphology of several such palms growing at Coimbatore. Furtado (1926-29) has seen coconut inflorescences where the axis was unbranched, the flowers being borne directly on them. Most of the flowers of this tree are female (Figs. ***130*** and ***131***). John and Narayana (1942) have counted upto 600 female flowers from one such inflorescence. A few male flowers are seen at the tip of the inflorescence and also along with the female flowers. Occasionally this inflorescence bears one lateral branch.

Partial suppression of spikes.

In this palm about half the number of the basal spikes of the inflorescence are reduced and sometimes these suppressed spikes are represented by one or two flowers only. A few spikes towards the distal half develop normally and bear usually male flowers. The main axis extends further, and this bears numerous female and male flowers (Davis, 1957).

Secondary branching.

The male coconut and the palm showing dimorphic sex have compound spadices as already explained.

Twin and fasciated spikes.

The occurrence of twin and fasciated spikes has been observed by Davis (1957 *a*). Twin spikes are formed either as a result of partial fusion of adjacent spikes or partial forking of a single spike. These spikes (Fig. ***132***) are quite normal and bear both female and male flowers. If the common stalk is sufficiently long, female flowers (one or a few) are borne on this region and if the forking takes place close to the basal end, the branches bear the female and male flowers.

Fasciation of the coconut spike is of a rather common occurrence. This phenomenon is usually caused by insect attack or similar injury to the spikes during the meristematic stage. Fig. ***133*** shows a few fasciated or flattened spikes. The stimulation which induces rapid growth of the spikes results in the expansion of its surface area. In many such instances, branching or rebranching of the spikes is also noticed. All the fasciated spikes shown here bear only male flowers which are generally sterile or underdeveloped.

Foliation of the spadix.

Ridley (1907), Furtado and Barreto (1920-21), Iyengar (1922-23), Burkill (1923-25), Sands (1927) and others have reported the conversion of flower bunches into vegetative shoots termed ' bulbils '. According to them, the abnormal condition was due to the foliation of the bracts of the inflorescence so that the latter was turned into a leafy branch. Furtado (1923-25) while considering the possibility of grouping a bulbilliferous coconut palm as a branched one, suggests that this is a case which ought to go under the title ' chloranthy ' or ' proliferation '. According to Petch and Gadd (1923), ' Virescence ', that is the conversion of the inflorescence into an axis bearing abnormal leaves is not uncommon, but these abnormal inflorescences die soon. Davis (1948) described a bulbilliferous coconut from South Travancore (India) which produced only ' bulbil-shoots ' instead of flower bunches.

Compound bulbils.

These are also met with in palms. Most of the bulbils of the palm reported by Davis produce secondary bulbils. The secondary bulbil is homologous with the rachis of a normal spadix.

Abnormalities of the flower

Development of the pistillode.

While the reduced androecium (ring of the staminodes) in a female flower develops and attains a bisexual condition, the pistillodes of male flowers in some rare coconuts develop to some conspicuous size. Furtado (1926-29) examined a spadix which had numerous banana-like fruits and only two nuts of normal shape. The normal nuts had developed from places where female flowers are generally located, while the former occupied the positions of male flowers. The banana-like fruits were apparently the result of the development of the usually abortive ovary of male flowers. Patel has also noticed such an abnormality on the West Coast of India. It is not known whether such fruits have any seed and if so, whether they are capable of germination.

Apocarpic ovary.

The female flower of a coconut has three carpels which are completely syncarpic till receptivity. There is no distinct style for the carpels. The small unbranched triangular stigma of each carpel is also not distinguished until receptivity. Apart from the free stigmata which persist on the fruit till maturity, the rest of the fruit develops united. The three carpels that constitute the fruit may easily be distinguished by the three ridges which run from the stigmatic end to the stalk-end. Further, three clear ridges and three ' eyes ' are present on the endocarp. Under rare circumstances, the coconut produces partial or completely apocarpic fruits. Davis and Menon state that all the fruits of the midget coconut palm have apocarpic fruits. Gadd (1924) describes abnormal female flowers of coconut where the three carpels were fused only at the base, being free to a greater or lesser extent at the apex. Costerus and Smith (1923 *a*) state that horns in coconut fruits are formed as a result of the apocarpic nature of the ovary. Davis has recorded certain interesting coconut fruits collected from Alleppey in Kerala (India) having completely free carpels. Apocarpy is considered a primitive character in plants and their rare occurrence in coconut might be regarded as atavism.

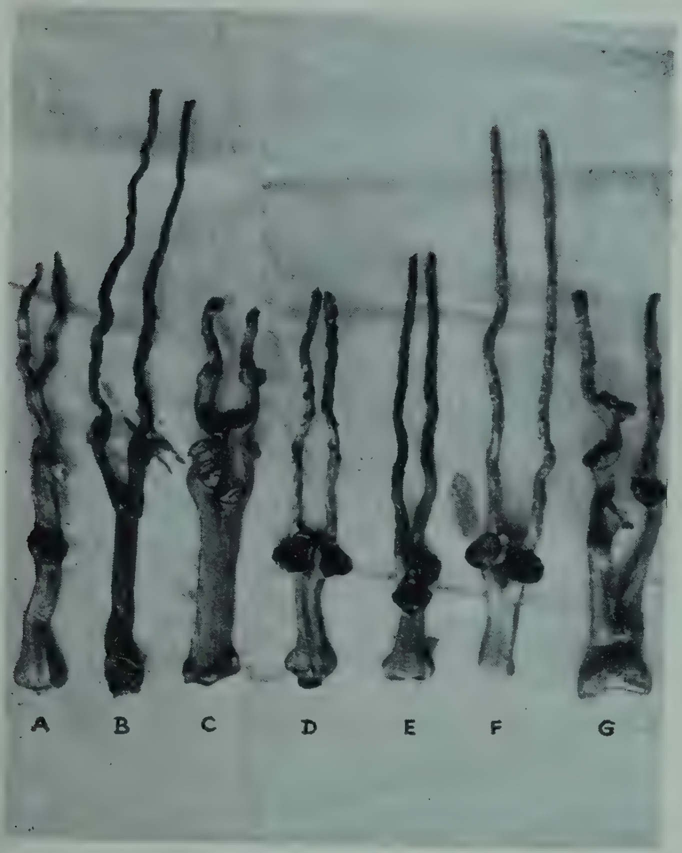


Fig. 132. Twin spikes

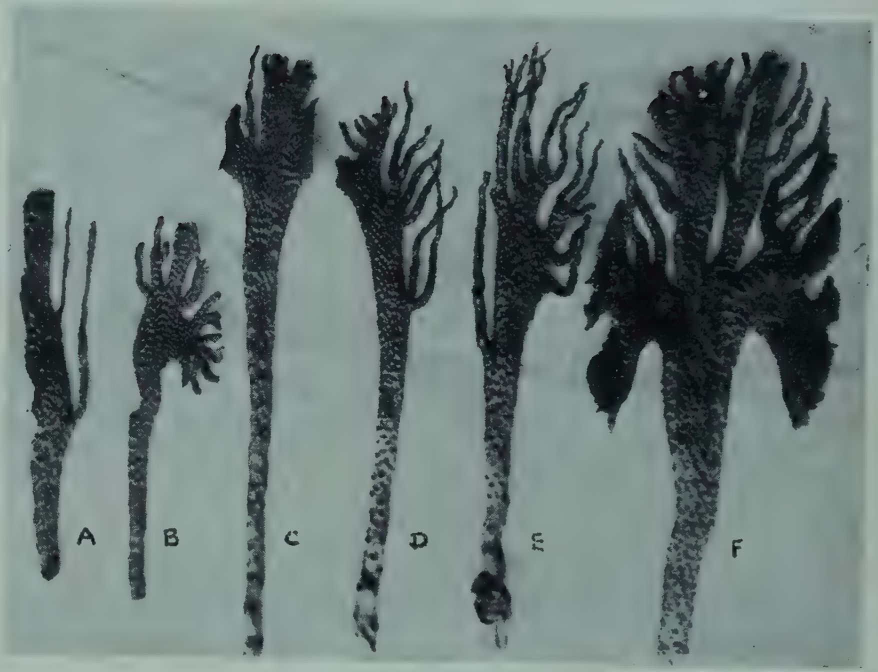


Fig. 133. Fasciated spikes

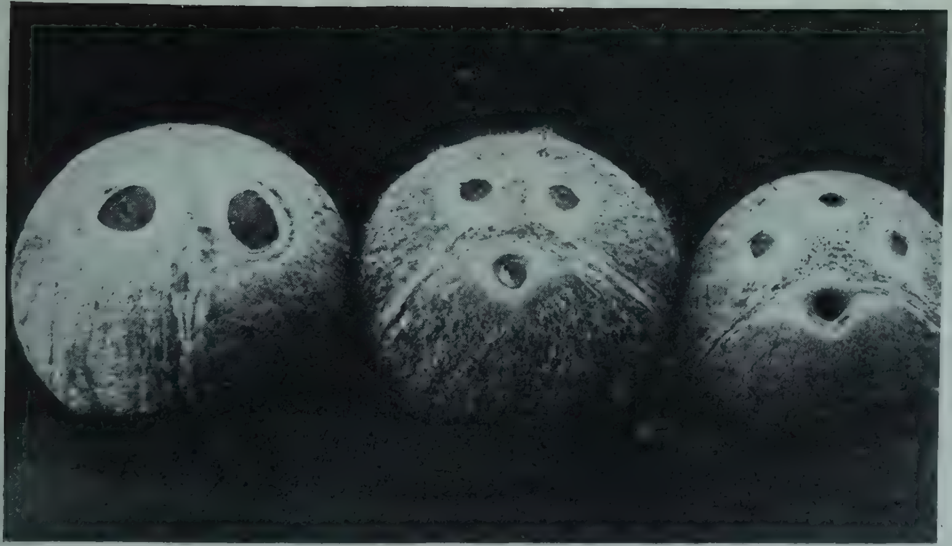


Fig. 134. Bi, tri and tetracarpic fruits

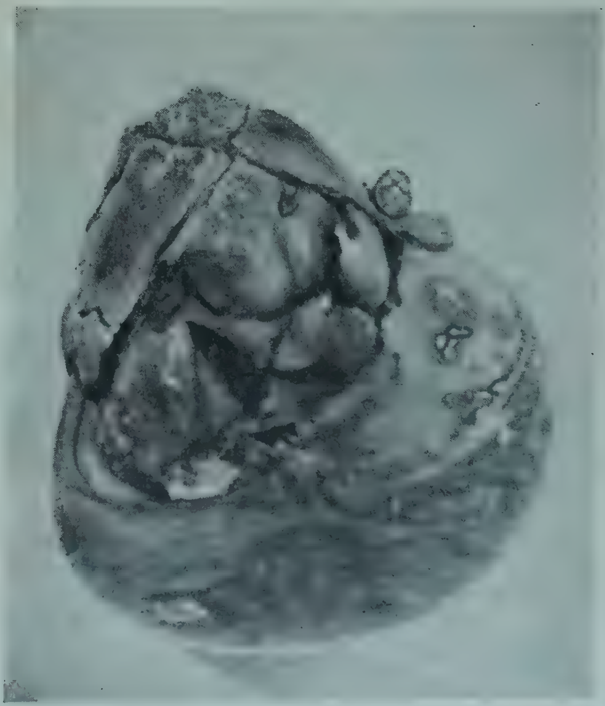


Fig. 135. Monocarpic fruit

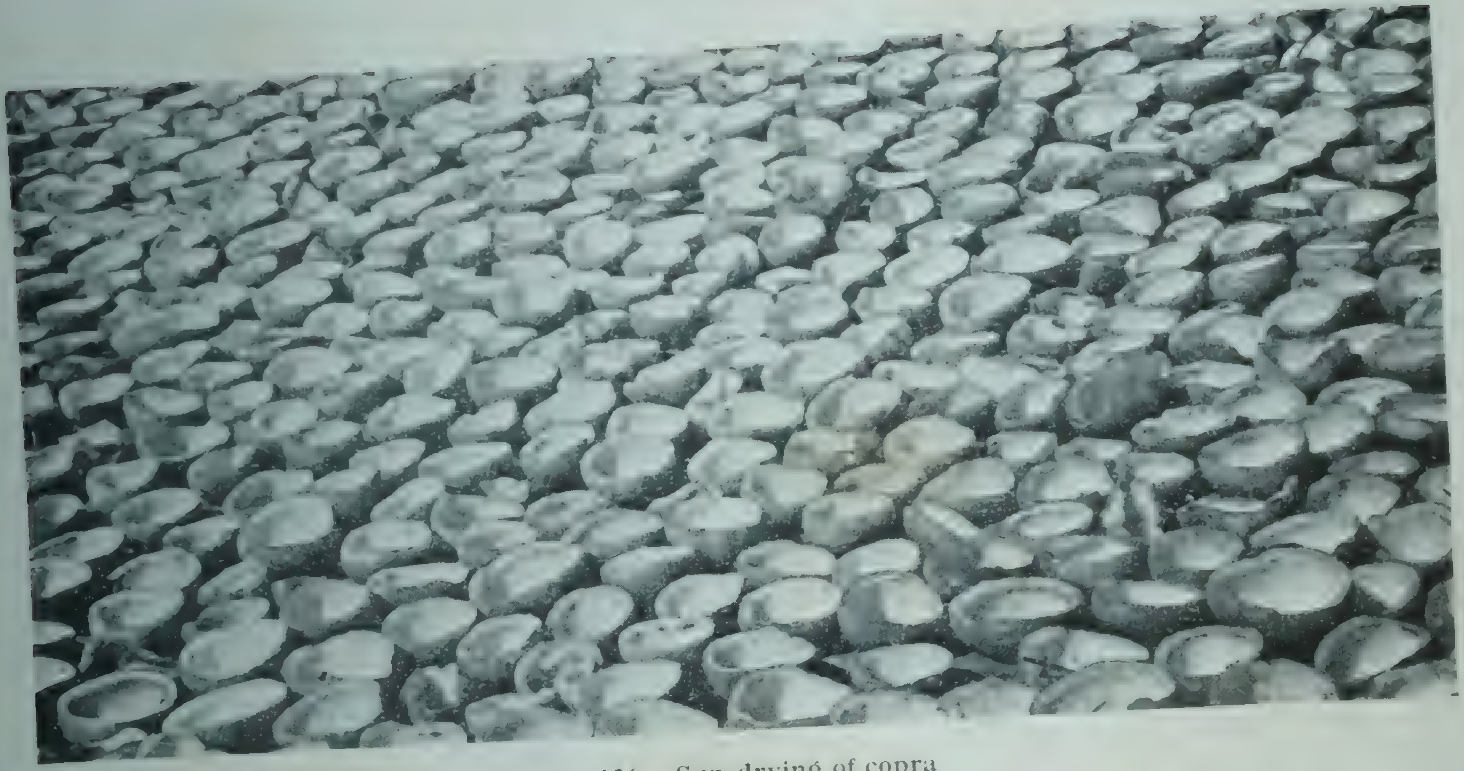


Fig. 136. Sun-drying of copra

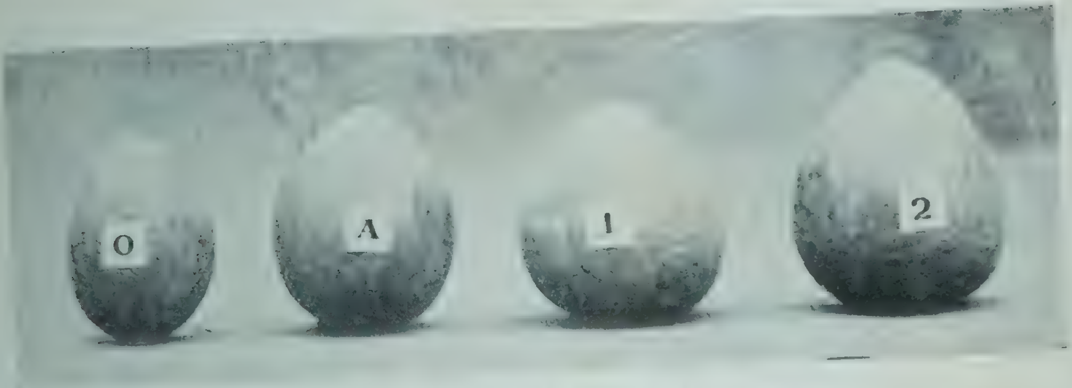


Fig. 137. Commercial grades of ball copra

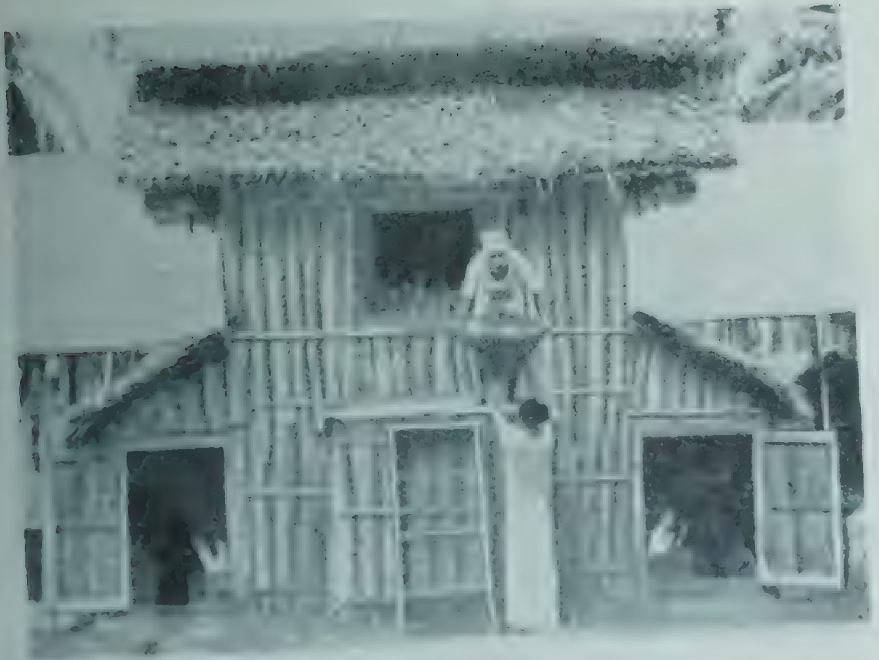


Fig. 138. Copra kiln for the small holder
(After Cooke, 1956)

Fig. 139. Coconut shells burning in serrated brick hearth
(After Cooke, 1956)

Polycarpy.

Each carpel of a coconut fruit is one-ovuled, but usually only one seed develops out of the tricarpic ovary. The developed seed has only one embryo and normally a single sprout is expected from a nut. However, some nuts are seen producing more than one shoot.

Jacob (1940) has described a two-seeded coconut fruit. The two seeds are separated by a leathery septum. The third ovule is aborted. Daniel Sundararaj (1952) cites an interesting specimen of a three-seeded coconut. Davis (1948 *b*) describes a coconut fruit giving rise to three shoots, one through each 'eye'. Here all the three 'eyes' are fertile, each 'eye' representing a developed seed. This condition may be regarded as polycarpy. Forbes (1879) has described a nut with fourteen carpels, all of which have germinated, producing a tree with fourteen stems united at the base.

Variation in the number of carpels.

Normally, a female flower has three united carpels each having an embryonic ovule. But in Fig. ***135*** is seen a rare young monocarpic fruit. Also a bicarpellate coconut fruit has been observed. The epicarp of this fruit had only two ridges and two stigmatic lobes. The endocarp of the fruit seen in the figure ***134*** has only two ridges and each carpel is indicated by a separate 'eye'. Some flowers of the midget palm also produced only two carpels. In figure ***134*** is also seen a tetracarpic fruit. The four carpels are clearly represented by the four 'eyes', the four distinct ridges on the endocarp and the tetragonous nature of the epicarp. The four stigmatic lobes which persist till the maturity of the fruit are also indicative of the four carpels. As usual, the fruit is only one-seeded. Here the biggest 'eye' is 'fertile' or 'soft'. Young coconut fruits having carpels ranging from four to ten have also been met with by Davis.

Variation in the number of perianth, stamens and pistillodes.

In the male flowers, there are three triangular and valvate sepals which are much smaller than the three valvate petals. The female flowers have three huge sepals which are convex outwards. The outermost one almost covers the entire flower during the early stages of development. Petals, numbering three, are smaller and thinner. Apart from the six perianths, a female flower has a bract and a bracteole. Davis has observed certain flowers, having numerous perianth parts and one of them has 13 individual perianths. The seventh perianth of the female flower recorded by Davis and Menon (1957) is the developed pistillode. Several male flowers having varying numbers of perianths have also been observed. Another flower was seen to have only 3 normal sized valvate sepals. But it had a single row of six large valvate petals. This flower had a single ring of 12 stamens with fully developed anthers. Also flowers with 10, 8 and 7 stamens have been observed. The peculiar flower having 12 anthers had six pistillodes in the centre instead of the usual three. Also, flowers possessing 4 and 5 pistillodes have been recorded.

Proliferation of the flowers.

Rare cases of spadices have been reported where the individual flowers vegetate to form bulbil-like shoots. Shortt (1885) has recorded a spadix, from one of whose flowers a shoot of leaves was thrown out with a slight tendency to fructification. They were later converted into " spring " leaves, apparently forming a young shoot. Andy (1870) has described a monstrosity which consisted in the phyllody of a greater portion of the female flowers in the spadix and not of the whole inflorescence itself. Davis (1948 *a*, 1954) recorded two trees showing 'chloranthy' from South Travancore. Here all the flowers both male and female showed a tendency to vegetate and some of the bunches bore as many as 500 bulbils. Each bulbil grew to about 15 cm to 22 cm by the time it dried up. Attempts to propagate these bulbils were not successful.

Viviparity.

Venkataraman (1928) observed an instance of bulbiferous spadix which he called parthenogenesis occurring in a coconut palm. The buttons or the young nuts in the spadix did not develop into normal fruits, but some of them grew into bulbils somewhat resembling miniature seedlings. This he traced to a very early stage before the spathe actually opened. Several of the buttons were unfertilised without any sign of endosperm whatsoever. The tender inflorescence examined revealed that some of the ovules had started to develop and had produced growth-primordia.

Abnormalities of the nut

Horned nuts.

Coconut fruits bearing flat horns usually ranging from one to six are a rare phenomenon. Development of the staminodes, duplication of the gynaecial segments, apocarpic nature of the ovary and hypertrophy of the perianth parts are often attributed to be the causes for the production of horns in coconut.

Furtado (1926-29) has observed three horned nuts, each having a horn-like structure measuring 13 cm long and 3 cm thick at the central portion. He had removed the perianth from the nut and found that this horn was due to the abnormal development of one side of the papery ring, the growth of the other half of the ring having become arrested at an early stage so that it was not visible when the perianth was still attached to the nut. The horn was cut open and was found to be full of fibrous tissues only. Recently Davis and Menon (1957) while explaining the morphology of the horns, described several cases of horned nuts developed from the staminodes, carpels and perianth parts.

Petch (1924) favours the view that horns are formed as a result of duplication of segments of gynoecium. Davis and Menon have noted a tree having a second whorl of three carpels apart from a regular papery ring. Often, one or two or even all the three carpels of the additional whorl develop into big horns and this may support the theory of Petch. Costerus and Smith (1923 *a*) describe some cases of horned coconuts which they consider to be instances of apocarpy. Apocarpic conditions of the coconut ovary has been recorded by Gadd (1924) and Davis and Menon (1953). The latter authors have further described some typical apocarpic fruits where the individual carpels have grown into structures similar to the horns. Some floral modifications, wherein the perianth parts of certain flowers have developed into thick horn-like structures have been recorded. The portion of the flower which usually develops into the gynoecium was foliated into a small " bulbil-shoot " in these interesting flowers. Modification of some perianth parts into fleshy horns perhaps lends support to Masters' (1869) view regarding the morphology of the coconut horn. Therefore, though the horns appear alike in form and perhaps in function, they are not homologous.

Double ovary.

Chandrasekharan and Sundararaj (1950) have reported a coconut fruit having an additional horn-like structure which represents an additional ovary. The authors state that when the fruit and the horn were sawn into two, the bigger fruit was observed to be normal with the epicarp, the fibrous mesocarp and the hard endocarp enclosing the kernel. The horn also possessed the above three distinct layers of the fruit ; but the endocarp was solid in structure and about 0·25 cm in thickness. It is stated that the normal ring of staminodes was visible and the possibility of the horn being the developed staminodes may be ruled out. Because of the presence of the endocarp, the authors attribute the extra development as an ovary and since both are covered by common perianths and a common ring of staminodes, this fruit is considered as having a double ovary.

Sweet husk.

Ordinarily, the husk of the coconut is very fibrous and astringent to taste due to considerable deposit of tannin. The pericarp of young buttons has to be normally sweet at least when it is very young. But due to the presence of a high percentage of tannin, the sweetness is masked. There are some palms which produce buttons whose pericarp has a higher sugar content. The tannin content in these nuts is also less and apart from that, the sugar content is more than that present in normal buttons as shown by analysis. Because of the high sugar content and low fibre content, the young buttons are sliced and eaten like sugarcane. Seasoned in vinegar, the pericarp of such young buttons forms good pickle. Another importance of this tree is that the husk of these nuts yields very fine and white-coloured fibre. The retting period of such husks is also comparatively less.

Abnormalities in kernel.

Some coconut palms are known to occur on the West Coast of India exhibiting a peculiar condition of the endosperm, which instead of being hard, is of curd-like consistency. Satyabalan (1953) had observed similar condition in a single nut (out of ten from a bunch) of the Philippine Laguna variety planted at Kasaragod. The internal surface of the kernel appeared warty or rugged and the kernel had less of fibrous matter. The kernel was not sweet but had some oily taste and flavour. There was no symptom of mould attack nor did it emit any bad odour, indicating decay. However, the seed had a normal embryo. The " makapuno " coconut described by Torres (1937) has some similarity to the coconut with buttery kernel. In " makapuno ", the meat almost fills the entire cavity of the shell. Patel has also referred to the stray occurrence of a nut characterised by the absence of the usual water, but filled with a jelly of the consistency of thick curd. This is locally known as *thairu thengai* (curd coconut). It is not definite whether both the *thairu thengai* and "makapuno" nuts are of the same type. A tree has been recently traced at Velayuthapuram, Rajapalayam (Madras) which often produces nuts with semi-solid kernel.

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CHAPTER XVII

UTILISATION OF COCONUT PRODUCTS

The fact that every part of the coconut palm is capable of being put to some important use or the other has already been mentioned. Some of the important aspects relating to the utilisation of coconuts are described in the following pages.

Tender coconuts

Tender coconuts are used in large numbers in all coconut producing countries. In India for instance, 55 million tender nuts are consumed annually (Gopalan, 1951). The tender nuts are valued both for the sweet water which is a refreshing drink and the gelatinous kernel which is a delicious food. The kernel is eaten as such or mixed with sugar or jaggery (*gur*) and beaten rice.

Mature nuts

The mature coconuts are used for copra making, for edible purposes as fresh kernel, for religious offerings and for raising seedlings.

It has been estimated (Gopalan, 1951) that 4,97,840 metric tons of mature coconut kernel are used for edible purposes in India. Coconut or " Sriphal " as it is called in religious parlance, occupies a very important place in Hindu ritual. It is considered a very auspicious fruit and often forms a part of the religious or sacrificial offerings. Coconuts are also given as presents in token of friendship, homage, respect or good-will on the occasion of Hindu marriages and other ceremonies.

COPRA

Copra (dried meat or kernel of the coconut) may be made both in the form of ' cups ' or ' balls '. A fair proportion of the coconut produced in the different countries is used for making copra. In India, 1,500 million nuts are used annually for this purpose.

Cup Copra

Cup copra is made either by sun drying or kiln drying.

Sun drying. Freshly harvested or stored nuts are husked and split into halves and the water in the cups drained. The cups are then kept close together out in the sun for drying with the kernel facing up. After about two or three days' drying, the kernels get more or less detached from the shells. They are removed from the shells, if necessary with the help of a thin wooden or other type of lever. The kernels are again dried for another four or five days. To obtain good quality copra, it is necessary to dry the cups in the sun continuously for five to seven days (Fig. ***136***).

During the period of drying, the drying ground is covered at night or when it rains. Large screens made of bamboo and coconut leaves or tarpaulins may be used for this purpose. In some drying yards wire or cotton netting is sometimes hung over the cups to prevent birds doing damage to the drying cups.

In India, sun drying is most often done on any clean ground or floor. But in Ceylon a drying floor (barbeque) is recommended (*Coconut Res. Inst., Ceylon, leaflets* Nos. 15 and 20).

Needless to state, bright sunny days are necessary to obtain copra of good quality. Copra made during the rainy or cloudy days may turn mouldy or discoloured. Nuts harvested during rainy season are therefore generally stored in specially constructed well-ventilated coconut stores. However, copra of fairly good quality can be made during the rainy season in properly designed copra kilns.

Kiln drying. Copra kilns of different sizes and shapes have been in use in different coconut producing countries. In primitive kilns, known as " Smoke driers ", the copra is heated directly by the hot gases of burning coconut shells. In these crude kilns very inferior smoked copra is obtained. Several improvements over these types of kilns have been made for preparing copra.

Cooke (1936 *a*, 1936 *b* and 1937) has described the details of construction and working of " 10 acre ", " 30 acre ", " 50 acre ", " 100 acre ", " 150 acre ", " 250 acre ", " 500 acre " and " 750 acre " kilns, the names indicating approximately the maximum acreage each kiln is intended to serve. These kilns were standardised under Malayan conditions. The Ceylon Copra Kiln having a total capacity of 10,000 nuts and allowing a daily intake of 2,500 nuts has been described in *leaflet* No. 15 of the *Coconut Res. Inst., Ceylon.* Details of design and operation of a Ceylon type small holder's copra kiln, capacity 1,500 nuts, made of cadjans (plaited coconut leaves), hardwood poles and light rafters (Fig. ***138***) have been furnished by Cooke (1956 *a*, 1956 *b*) and in *leaflet* No. 23 of the *Coconut Res. Inst., Ceylon.* Verghese and Thomas (1952) have standardised a copra kiln suitable for small coconut plantations in India.

In these kilns, good quality coconut shells from mature nuts, dry and free from husk and of even size are interlocked and laid loosely in single or double rows in serrated brick hearths (Fig. ***139***). In order to avoid excessive production of smoke when the chain of shells is first lit, some shells are ignited outside the kiln and brought in when they are burning fiercely. The shells burn without smoke. The hot air heats uniformly the split halves of coconuts arranged with the kernel facing up, on suitable platforms. When the kernels show signs of detachment from the shells, the split halves are taken out and separated into shells and kernels. The kernels are then reloaded on the platforms and the process of drying continued till crisp copra is obtained. In small-sized kilns suitable for small holdings, the kiln is sometimes provided with a heat spreader above the fire pit in order to spread the heat uniformly. Grills of wire mesh or split areca stem are also used as copra platforms. Cooke recommends the preliminary sun drying on a barbeque before the split halves are loaded in the kiln.

The total drying time for producing good quality copra and the number and intensity of the fires required depend on a number of factors the most important of which are :—

(*a*) the size and capacity of the kiln,

(*b*) the number and size of the nuts comprising the charge,

(*c*) the size of the shells used for fuel,

(*d*) the dryness of the shells,

(*e*) the packing of the shells,

(*f*) the adequacy or otherwise of ventilation and

(*g*) the weather conditions.

Total drying time ranging from 15 to 40 hours has been reported for different types of kilns.

It must however be admitted that the copra obtained from many of these driers is not completely free from smoke. Whiter copra is obtained by using coconut shell charcoal instead of coconut shells as fuel.

In recent times, several types of copra kilns for making white copra, perfectly free from blemishes of smoke have been patented. The ' Chula ' patent copra-drier is one such type. In this kiln any kind of fuel—coconut shells, husks, petioles, firewood, etc., is burnt in a fire-place. The hot gases pass through suitable flue pipes connected to a chimney which permits the escape of smoke to the outside. Cold air is let in to pass over the hot flue pipes and the hot air is blown by means of a fan through a bed of split coconuts loaded in a drying chamber. Pearson's patented kiln (Menon, 1948) and the Rotary Louver Drier (Kuruvila, 1948) are some other models for the preparation of white copra.

Pieris (1955) has given details of (1) the standard Ceylon drier for large and small-scale drying, (2) Seychelles hot-air drier for small-scale drying, (3) the New Guinea or German drier for large and small-scale drying, (4) Pearson's patent hot air drier for large scale drying and (5) the ' Chula ' hot air drier for large scale drying.

Recently Howard (1956) has surveyed the copra industry of Ceylon, Singapore, Malaya, Indonesia, the Philippines, Papua and New Guinea, the Solomon Islands, Fiji, Tonga and Western Samoa with a view: (1) to study copra production methods and reasons for the great variation in the quality of copra exported to Europe, (2) to study steps being taken in different territories to improve quality, (3) to discuss the possibility of further improvement and ways and means of achieving it, and (4) to discuss the effects of poor quality copra on the production of edible oils, processing problems and developments in British Seed Crushing Mills. The various methods of harvesting, husking, cracking and drying are critically compared and problems associated with the moisture content of the copra and with dust, sulphur and smoke contamination are discussed. Suggestions are made for improvements and for further investigational work. The various types of driers in use are described and detailed sketch plans are provided for four of them, namely the Standard Ceylon Copra Kiln, the De Vapour Driers (both single and multiple), the Kukum Hot-air Drier and the New Zealand Reparation Estate Copra Drier.

Ball Copra

Copra in the form of balls is made from whole unsplit nuts. Verghese *et al.* (1955) have described the method of preparation of ball copra. The process consists in storing coconuts with husk in a suitable ball copra store which is usually a two storeyed brick and mortar building, the floor and four sides of the top floor being made of wooden bars spaced three to four inches apart. The size of the store varies according to the requirements of the producer. Usually there are five or six compartments 3·66 m × 3·66 m × 1·83 m, each compartment holding 4,000 to 5,000 nuts. Small-scale manufacturers also use a wooden platform over the kitchen fire-place.

Fully ripe nuts, 12 to 14 months old, are harvested and thrown into the wooden upper floor of the store. They are frequently stirred and/or smoked till they are quite dry. The proper stage of drying is determined by shaking the nut when the detached kernel makes a rattling sound. After the rattling stage, the nuts are stored for some more time and then husked and shelled and suitably marketed. Commercial grades of ball copra are illustrated in Fig. *137*. The smoking is done by burning paddy husk, coconut husk, dry leaves or cheap firewood in the ground floor of the store. The entire process takes 8 to 12 months. Verghese *et al.* have shown that small sized nuts are best suited for making ball copra.

Yield of copra

The yield of copra is found to be influenced by a number of factors such as the maturity of the nuts, the season of harvesting, the period of storage of nuts, the age and the inherent character of the palm, and soil and climatic conditions. In India, the yield is found to vary from tract to tract. Thus to make a ton (1,016 kg) of copra, 6,222 nuts are required in Malabar and South Kanara 7,000 in Godavari, 6,850 in Travancore-Cochin and 8,000 in Mysore. It is reported (*Report Marketing India*, 1943) that 4,800 nuts go to make a ton of copra in Ceylon while 6,250 and 4,500 nuts respectively are required in the West Indies and the Philippines.

Pieris (1935) found for dead ripe nuts under optimum drying conditions, the weight of copra to be 33⅓ per cent of the weight of husked nuts. Verghese and Thomas (1952) found the yield of copra to be 40·64 ± 2·10 per cent of the weight of husked and split nuts (nuts without the nut water).

Grading

Copra is usually graded on considerations of colour, cleanliness, moisture content, size and mouldiness. Several grade specifications and trade names are in vogue in different countries. Standard contract terms for milling copra have been prescribed by the Government of India (*Indian Coconut J.*, 1950).

Uses

Copra is used for edible purposes and for extracting coconut oil. Copra is eaten as such or mixed with other dry fruits. It is also used in the preparation of sweets and as a garnish in many dishes. Copra balls are used as religious offerings and on ceremonial occasions.

Desiccated coconut

Desiccated coconut is prepared from coconut by first removing the husk and shell, then parrying off the brown skin from the kernel and passing the white meat through cutting or shredding machines of various types to produce chips or threads of varying degrees of fineness. These are finally dried in hot air driers and packed for export in tin-lined cases similar to tea chests. Desiccated coconut finds use in the preparation of confectionery, cakes, biscuits, pastry, puddings, etc.

It is reported (*Indian Coconut J.*, 1951) that desiccated coconut is marketed in the U.S.A. under several trade names such as " maccaroon ", " thread " and " ribbon ". In Ceylon 6,900 nuts will yield one ton of desiccated coconut (*Ceylon Coconut Quart.*, 1952).

" Tend-O-nut "

" Tend-O-nut " is the trade name given to desiccated coconut subjected to a tenderising and sweetening process. " Tend-O-nut " is now manufactured in Ceylon (*Indian Coconut J.*, 1951).

To every 36 kg of shredded or disintegrated coconut made tender by the addition of a special chemical solution, 12 kg of sugar and 84 gm of table salt are added. When all the ingredients are thoroughly mixed, the processed coconut is dried in desiccators at a temperature of about 90°C. The product is dried in the desiccators for about twice the time as ordinary desiccated coconut. After the drying process is over, the " Tend-O-nut " is sorted into two grades and packed in wooden cases ready for export.

" Tend-O-nut " contains 60 per cent pure coconut, 38 per cent sugar and 2 per cent moisture. It is manufactured in about seven pleasant colours : rose, pink, brown, green, yellow, maroon and mauve.

" Tend-O-nut " is a delicious centre in sweets and used for sprinkling or decorating cakes or as cake filling. It can be eaten without further preparation, mixed with warm milk, tea or water just enough to soften it.

COCONUT OIL

Though copra is put to some edible use, the main proportion of the copra produced in the different countries is milled for oil. In India, 80 per cent of the copra produced is so utilised.

Milling

Copra is crushed both by village " Chekkus " or " ghannies " and power mills equipped with rotaries and/or expellers.

The " Chekku "

The " chekku " or " ghanny " consists of a fixed wooden or stone mortar, inside which revolves a wooden pestle, leaning against the side of the mortar. The extraction of the oil takes place within the mortar as a result of friction caused by the revolving pestle on which pressure is regulated by means of a lever and weights. The " chekku " is usually driven by one or two bullocks, but small " chekkus " are sometimes worked by human labour also. The capacity of the " chekku " usually varies according to the size of the mortar but generally a bullock-driven " chekku " crushes from about 50 kg to 80 kg of copra per day of 10 hours. The daily capacity of a " chekku " driven by human labour is about 20 kg.

Rotary mills

Rotary mills may be described as power driven " chekkus " with the difference that in the case of the rotary mills both the mortar and the pestle revolve. In coconut producing areas, these mills have largely displaced " chekkus ". Rotaries invariably work in pairs and their number in individual copra crushing establishments vary from one pair to several dozen pairs. The capacity of a rotary mill usually varies from about 250 kg to 325 kg of copra per day of 10 hours. About $\frac{1}{4}$ kg of *gum Acacia* is added per maund (40 kg) of copra to bind the cake and facilitate extraction of oil.

Expellers

Expellers are used only in the larger mills. The number of expellers in individual mills vary from one to six. The extraction of oil in an expeller takes place within a steel case by means of a series of hardened steel worms, so arranged on a revolving shaft as to produce increasing pressure as the copra is carried from one end of the case to the other. The capacity of an ordinary sized expeller is usually about two to three tons of copra per day of 10 hours, but there are a few big expellers of larger capacity in some mills.

Other methods

Good quality coconut oil can be prepared from coconut kernel without converting it into copra. Several patents have been taken out for this purpose. In one method (*Food Engng.*, 1952) the intractable protein envelope enclosing the oil globule in the fresh meat is broken by carefully controlled enzyme action followed by rupturing the envelope by chilling. The oil is removed by centrifuging and is ready for storage after filtering. Refining is unnecessary and there are no losses through chemical deterioration. Overall recovery in terms of fresh meat is reported to be 10 per cent higher than that for copra.

On a small-scale, coconut oil of superior quality can be prepared from fresh grated coconut kernel. The grated kernel is squeezed with water and the coconut milk thus obtained is concentrated to oil by evaporation in suitable iron or bronze boiling pans. The oil thus prepared is sweet-scented and light in colour. It has been shown by Armstrong *et al.* (1925), Allan and Moore (1925) and others that the oil from the outer brownish-yellow skin or testa of the coconut kernel contains a greater percentage of glycerides of unsaturated acids than the oil from the endosperm, and is of inferior quality. The removal of this brownish layer in grating coconuts for the preparation of oil as described above will result in white oil of extra superior quality. Poor people of the Malabar Coast, India, use this oil as a substitute for ghee and for medicinal purposes. This is also true of the ' white oil ' obtained by crushing the ' white meat ' after converting it into desiccated coconut as opposed to the inferior quality " parrying oil ".

Solvent extraction

Considerable quantities of coconut oil may be recovered from the coconut oil cake by extraction with suitable hydrocarbon solvents like benzine and hexane. Details of machinery required and the process of solvent extraction have been described by Maddi Sudarsanam (1951), Ghosh (1953) and others.

REFINING COCONUT OIL

The term ' refining ' with reference to a vegetable oil is understood in more than one way. As commonly understood it includes (1) removal of suspended non-oily impurities, (2) removal of partially dissolved impurities and (3) removal of free fatty acids in the oil almost completely or bringing down the concentration of free fatty acids to the required minimum. Refining of an edible oil, as technologically understood, means (*a*) removal of suspended impurities, (*b*) removal of phosphatides, mucilaginous matter, etc., (*c*) removal of free fatty acids, (*d*) removal of colouring matter by bleaching and (*e*) removal of objectionable odoriferous impurities present in the oil by ' deodorisation '. The different processes reported by John (1957) are as follows :—

(*a*) Removal of suspended impurities

It is mostly carried out by filtering the crude oil through filter presses. Thick, specially woven variety of cloth is used as the filter medium, and to accelerate the process of filtration and to produce more clear filtrate, filter aid like ' Hyflo Supercel ' is used. Mostly the suspended matter consists of fragments of extraneous matter. Filtration is conducted above 25°C to 30°C, since, below this temperature, the viscosity of oil, or its hardening tendencies at lower temperature retard the speed of filtration. The filtrate is cooled well and examined for clarity.

(*b*) Removal of phosphatides, mucilaginous matter, etc.

Many of these impurities are soluble to some extent in the oil when they are anhydrous and become insoluble when hydrated. This principle is adopted in the process of the removal of mucilaginous matter, proteins or protein fragments and phosphatides. While the oil is in a hot condition, plain boiling water, or brine of low sodium chloride content is allowed to mix with it in small proportion, the contents of the vessel in which this treatment is done being continuously stirred. The hydrated material gets separated, and after discontinuing the stirring, a copious quantity of boiling water is allowed to fall on top of the oil, which while going down due to its increased density, takes along with it the hydrated compounds. As far as coconut oil is concerned, a 5 to 10 per cent solution of common salt gives good results. After removing these substances, the oil is washed again with hot water.

(*c*) Removal of free fatty acids

Free fatty acids that are found in varying degrees in vegetable oils are removed by allowing these acids to react with caustic soda solution under controlled conditions, subsequently removing the soap formed, and washing the oil layer free of any soap with boiling water. In actual practice, calculated quantity of caustic soda made into solution of required strength varying according to the variety of and the percentage of free fatty acids in the oil, is allowed to mix with the oil at elevated temperatures. The temperature of neutralisation depends upon the quality of the oil and its free fatty acid content. The conditions are so maintained that the minimum possible quantity of neutral glyceride is attacked by the caustic alkali. The soap formed settles down along with the boiling water added after addition of alkali, and is removed from the bottom of the refining tank. The oil is then freed from soap by sufficient number of washings with boiling water.

(*d*) Drying of the oil and removal of the colouring matter

The neutralised oil, after it has been washed free from soap, is pumped into the bleacher, which is put under vacuum. The oil is dried thoroughly, cooled and bleached at the requisite temperature with

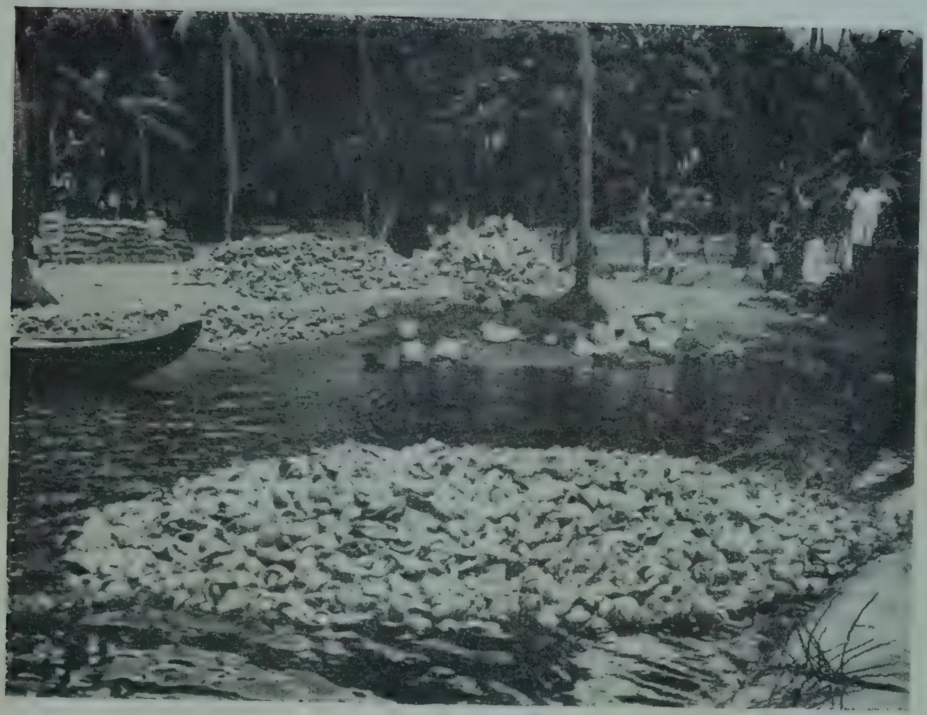

Fig. 140. Retting of husk

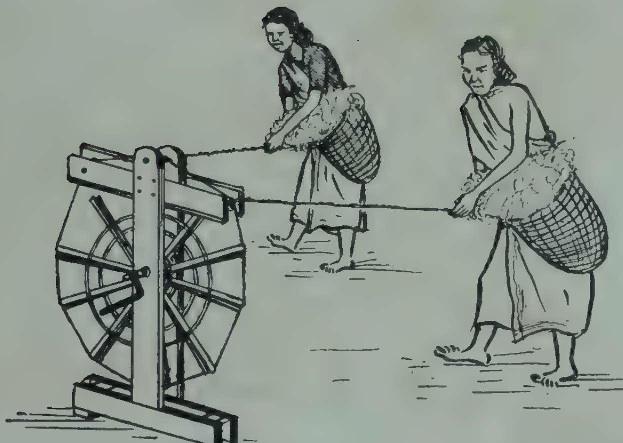

Fig. 141. Wheel spinning of coir

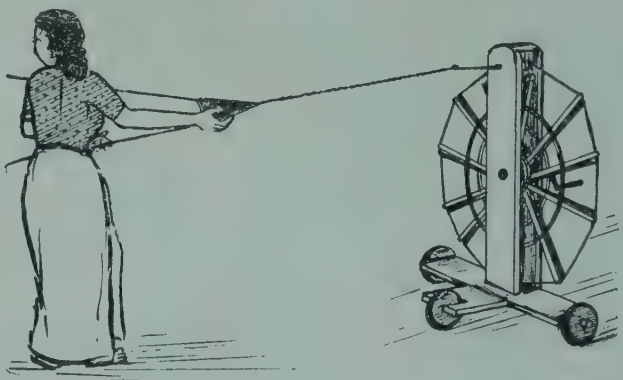

Fig. 142. Wheel spinning of coir

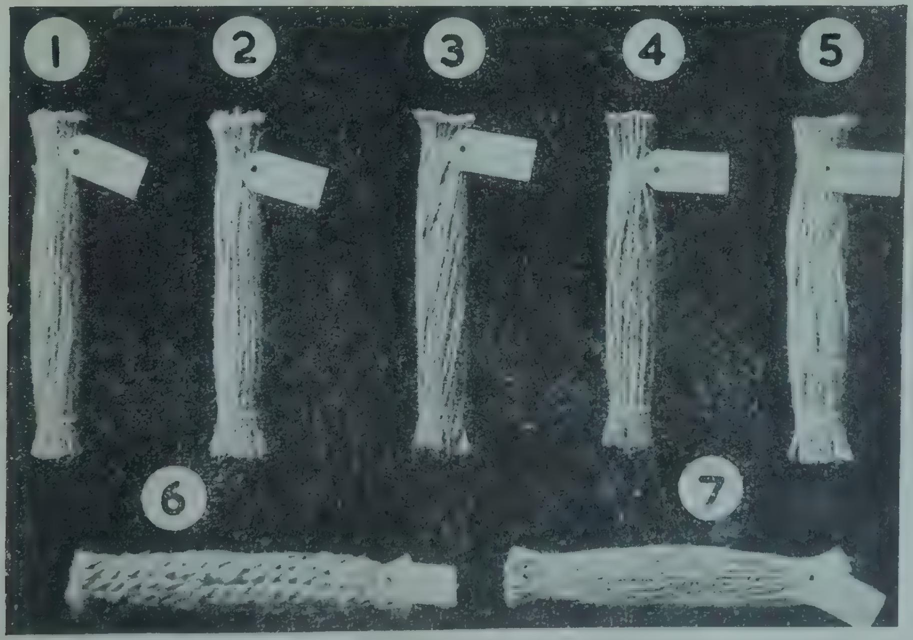

Fig. 143. Different types of coir yarn
(From Coconut Marketing Report, Govt. of India, 1943)

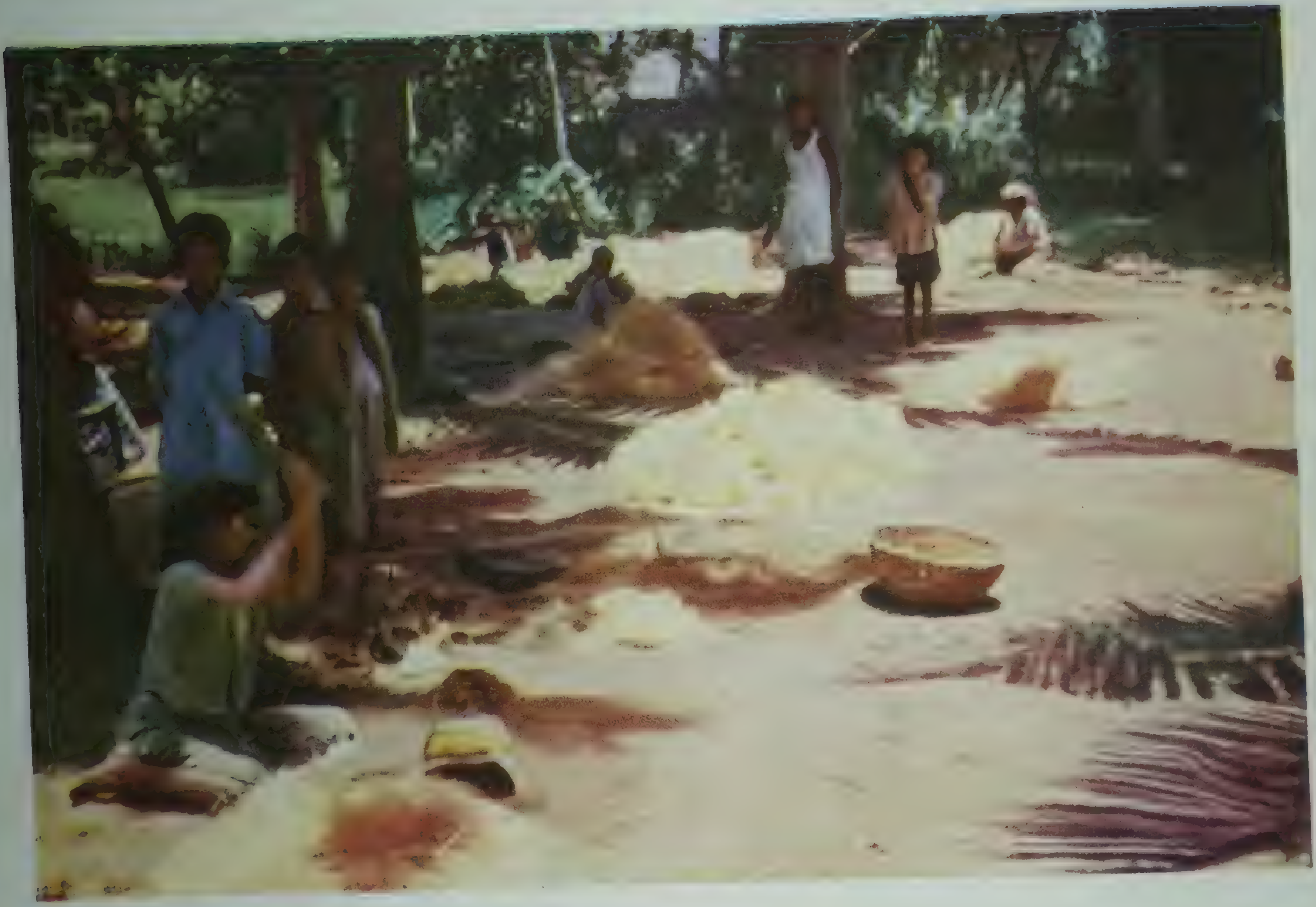

Fig. 144. Extraction of fibre

activated Fuller's Earth and carbon; the quantities of the bleaching materials used depend on the quality of the oil. Bleaching of oils by adsorption involves the removal of pigments which are dissolved in the oil. The neutralised and bleached oil is filtered 'clear' through filter press into storage tanks.

(*e*) Deodorisation

This is essentially a process of steam distillation, wherein relatively volatile odoriferous and flavoured substances are stripped from the relatively non-volatile oil. The operation is carried out at a high temperature to increase the volatility of the odoriferous components. The application of reduced pressure during the operation protects the hot oil from atmospheric oxidation, prevents undue hydrolysis of the oil by the steam and greatly reduces the quantity of steam required.

Vacuum is pulled on the deodoriser through a system of ejectors and barometric condenser and the refined and bleached oil is sucked into it. Superheated steam is allowed to pass through the hot oil under controlled conditions of vacuum and temperature for several hours until the oil is odourless. An anti-oxidant is added to the deodorised oil to improve its keeping quality. The deodorised oil is then cooled, pumped to a storage tank and filtered through an enclosed filter press into storage tanks so as to avoid contamination with external impurities like dust. The filtered oil is perfectly clear, colourless, and odourless.

Yield

The yield of oil varies with the oil content of the copra and the efficiency of the method and machinery employed. In India, the yield of oil was generally found to vary from 58 to 60 per cent when crushing was done in "chekkus", 62 to 63 per cent in rotaries and from 63 to 65 per cent in expellers. The average yield of oil of copra crushed in India by different methods is estimated to be 62 per cent.

Grading

Grade specifications have been prescribed for coconut oil in almost all countries. The Government of India (*Indian Coconut J.*, 1950) have prescribed standard grade specifications for the Indian coconut oil. These standards are in fair agreement with standards fixed in other countries.

Standard specifications for refined oil are:

(*i*) The oil shall be the genuine refined product obtained by expression from the kernel of the coconut, i.e., copra and shall be free from admixture with other oils or fats. It shall be clear and free from sediment and suspended matter.

(*ii*) Specific gravity at 40°C/30°C: 0·909 to 0·913.

(*iii*) Refractive index at 40°C = 1·4480 to 1·4492.

(*iv*) Saponification value = not lower than 250.

(*v*) Iodine value = 7·5 to 9·5.

(*vi*) Unsaponifiable matter = not higher than 0·5 per cent.

(*vii*) Colour = Not deeper than 1Y and 0·2R in 1″ cell on Lovibond Tintometer scale.

(*viii*) Acid value = Not higher than 0·5 per cent.

For grade I oil which is of slightly lower quality than the refined oil, a slightly deeper colour, viz., 1·5Y and 0·5R in 1″ cell of the Lovibond Tintometer scale has been permitted as also a higher acid value up to a maximum of 2·0 per cent. The other grades are grade II, commercial 'A' and commercial 'B' of lower quality standards.

Uses

Coconut oil finds a ready use for the following purposes :—

1. For edible purposes—*see* under "*Coconut Products as Food*".
2. Toilet and cosmetic purposes.

The use of coconut oil for toilet purposes is very popular. In South India, particularly on the West Coast, it is used in almost every household, both for bath and for dressing the hair. Even infants are rubbed with the oil specially prepared from fresh coconuts, before bathing, as it tends to give a softness and suppleness to the skin. By the process of deodorisation, the characteristic smell of the oil can be removed and if it is suitably perfumed thereafter, it makes an ideal oil for daily toilet. Several brands of hair oil perfumed with various delicate scents are offered for sale.

3. Manufacture of cosmetics such as face creams, shampoos, etc.
4. Manufacture of soaps.

Coconut oil is the most important vegetable oil used in soap-making. The properties of coconut oil have been mentioned below under ' coconut products as food '. While most oils and fats consist mostly of glycerides of fatty acids called palmitic, stearic and oleic, the principal fatty acids of coconut oil are lauric and myristic which are of lower molecular weights. Hence, the oil is easily saponifiable even in the cold. This property, viz., the ability of coconut oil to combine with alkalies such as caustic soda (in solutions of proper concentrations) even in the cold has made it the most widely used oil for the manufacture of cold process soaps on a cottage basis in India and other countries.

Coconut oil possesses a very high saponification value (250 to 260) and a very low iodine value (7·5 to 9·5) and in these respects it differs very much from other common oils and fats which have saponification values ranging from 180 to 200 and iodine value 40 to 200. The high saponification value coupled with the very low iodine value gives it a very high hardness number. (Hardness number means saponification value *minus* iodine value.) Therefore, the soap made with it is extremely hard and as such, coconut oil gives the soap a body and stability which no other oil (except palm kernel oil) can.

The coconut oil soap is very hard, white in colour and produces an excellent lather. The soap lathers freely in hard and saline waters and hence it is used in the manufacture of marine soaps. Another peculiarity of coconut oil is that the soap made with it is capable of taking filling materials like silicates, soda ash, earths, etc. The oil blends well with other oils and fats to give soaps of varying kinds. It can be used to the extent of 20 to 40 per cent in washing soaps, 15 to 25 per cent in toilet soaps and in varying proportions in others. In soaps made by cottage soap makers, it forms the principal ingredient and is used in quantities ranging from 50 to 100 per cent. Thus on a rough computation, it may be said that it forms about 30 to 40 per cent of the entire oil charge in soaps.

At present, the quantity of coconut oil consumed in the soap industry in India has been computed to be 25,000 to 30,000 metric tons.

5. As illuminant and lubricant.

Coconut oil does not leave a smoky flame if used in open lamps with wicks. Thus, it finds extensive use as an illuminant.

The use of coconut oil as lubricant is very limited.

6. For the manufacture of margarine.

Further uses of the oil as communicated by Kurup (1956) are:

7. Synthetic rubber manufacture. A sizable quantity of coconut oil is used in the manufacture of mercaptan, one of the important ingredients of synthetic rubber. There is no approved substitute.
8. In chemical warfare.
9. In the manufacture of hydraulic brake fluid for aeroplanes. The exact manner of usage is a military secret.
10. As a plasticiser in the manufacture of superior safety glass, non-clouding at low temperatures, for aeroplanes, tanks, trucks and automobiles. It is also used as a plasticiser in celullose acetate moulding powder for the manufacture of auto-trucks, aeroplanes, tanks and radio parts.
11. As an additive in processed form for lubricants. Certain higher alcohols produced from coconut oil are used as film strengthening agents for high pressure diesel engine lubricants. This film strengthening greatly increases the efficiency and utility of the oil lubricant.
12. Manufacture of synthetic resins.

One of the important uses of these resins is in the production of lining of food containers, the use of which is indispensable during the shortage of tin.

13. Manufacture of insecticides and germicides. Quaternary ammonium made from coconut oil is used in the production of the navy germicide, Tetrosan.

14. In the floatation process in the mining of materials such as potash. The processed coconut oil acts as a surface agent and by removal of the surface film permits of a more complete separation of the potash from extraneous materials than would otherwise be possible. It is also used in the mining of molybdenum.
15. As a plasticiser in the manufacture of rubber substitutes of the poly-vinylchloride type of resin.
16. In the manufacture of vulcanised rubber goods such as tyres. Lauric acid produced from coconut oil is employed for the production of zinc laurate which is used to shorten materially the vulcanising process in the production of automobile tyres.
17. In the production of sulphonated higher alcohols which in turn are employed in such important ways as (*a*) wetting agent in the paper and pulp industries, (*b*) as drying agent for textiles and leather, (*c*) in electroplating, (*d*) in insulating materials, etc.
18. Glycerine. Coconut oil yields 40 per cent more glycerine than most of the other oils.

Coconut oil-cake

Coconut oil-cake or *poonac* is the residue left after extracting oil from copra. The yield of cake may be reckoned to vary from 33 to 40 per cent of the copra.

Coconut oil-cake is utilised mainly as cattle feed. It is also reported to be used for human consumption. It finds a limited use as manure.

COCONUT PRODUCTS AS FOOD

Coconut products are extensively used in India, Ceylon, Netherlands, Malaya and other countries as articles of food. According to Gopalan (1951) 12,192 metric tons of tender coconuts, 4,97,840 metric tons of mature coconuts, 87,376 metric tons of edible copra and 2,17,424 metric tons of coconut oil—all expressed in terms of the kernel—in addition to small amounts of desiccated coconut and appreciable amounts of coconut jaggery are consumed annually in India. The total consumption in different forms amounts to 2,893 million nuts or about 84 per cent of the total nuts produced in the country. The reason for such large-scale home consumption of coconuts is no doubt due to its palatability and easy availability.

Highly exaggerated captions like " Coconut Milk—a wholesome and complete food ", " The Coconut—a source of all vitamins and minerals, necessary for health ", etc., have very often been put forward. A correct appraisal of the food values of coconut products in respect of fats, proteins, carbohydrates, minerals and vitamins therefore appears to be necessary.

Fat

Coconut fat or coconut oil in popular parlance is made up of the following fatty acids combined with glycerol.

Saturated	Caprylic	8·34 per cent
	Capric	7·19 ,,
	Lauric	47·31 ,,
	Myristic	17·00 ,,
	Palmitic	8·85 ,,
	Stearic	2·27 ,,
Unsaturated	Oleic	6·27 ,,
	Linoleic	1·80 ,,

Collin and Hilditch (1928) found the glyceryl esters to be:

Fully saturated glycerides	84 per cent
Mono-oleo-di saturated glycerides	12 ,,
Di-oleo-mono saturated glycerides	4 ,,

The oil is more or less constant in composition. This together with the nature of the glyceryl esters and other properties makes it highly nutritive. Basu and Nath (1946) give the following values for the coefficient of digestibility of coconut oil and other fats.

Coconut oil	99·3
Groundnut oil	99·0
Sesame oil	95·8
Mustard oil	94·1
Cow butter fat	97·2
Buffalo butter fat	96·5
Dalda vanaspathi	89·8

These results confirm the observations of other workers—Wesson (1919), Holmes (1919) and Langworthy (1923)—who have reported a digestibility coefficient of 97 to 99. Hartwell (1938) has shown that coconut oil is digested by pancreatic lipase more rapidly than any other fat including butter, and Godbole and Sadagopal (1951) found that coconut oil contains 91·0 per cent assimilable glycerides while cow's milk contains 63 per cent, buffalo's milk 56 per cent, beef fat 48 per cent and mutton tallow 45 per cent. Besides, certain unsaturated acids have been shown to be essential for health and coconut oil contains them in fair amounts.

Proteins

The coconut oil-cake or *poonac* is one of the important sources of vegetable proteins. In fact it is a protein concentrate. Joachim (1924), Child (1939 *a*), Cooke (1951) and others have reported 18 to 21 per cent of proteins in Ceylon coconut cake, while Patel (1938) has found 21·6 per cent of crude proteins and 20·49 per cent of true proteins in samples of coconut oil-cake from India.

The amino-acid composition of coconut proteins—Jones and Johns (1920), Jones *et al.* (1919, 1924), Desikachar and De (1947)—is as follows:—

Arginine	15·92 per cent
Histidine	2·42 ,,
Lysine	5·80 ,,
Tyrosine	3·18 ,,
Phenyl alanine	2·05 ,,
Tryptophane	1·25 ,,
Cystine	1·44 ,,
Methionine	1·43 ,,
Leucine	5·96 ,,
Valine	3·57 ,,
Alanine	4·11 ,,
Proline	5·54 ,,
Serine	1·76 ,,
Aspartic acid	5·12 ,,
Glutamic acid	19·07 ,,

Appreciable amounts of threonine and isoleucine have also been reported.

Mitchel *et al.* (1943) and Swaminathan (1937) found that at 10 per cent level in-take, coconut protein has a biological value of 71 to 77 and a digestibility coefficient of 86 to 94 per cent. Coconut proteins are thus seen to possess a high biological value. They contain many of the essential amino-acids in fair amounts, an observation confirmed by Jones, Finks and Gersdorff (1919) who have shown that the protein of the endosperm of the coconut contains all basic amino-acids essential for growth and maintenance. Child (1939 *a*) found that coconut *poonac* furnishes necessary proteins for growth at almost normal rate and Cooke (1951) has reported that coconut protein is fairly satisfactory as a food and will produce normal growth even when used as the only source of protein provided the diet is complete in other respects. Mitchel (1946) has shown that solvent extraction of coconut at a temperature not exceeding 70°C yields a product whose protein is 86 per cent digestible and has a biological value of 71 which is considered greater than the value for the kernel subject to drastic treatment. Nicols (1945) further found that the kernel contains less than five per cent of proteins of too low digestibility and biological value for use by children.

The digestibility of the whole nut has been reported by Cajori cited by Gopalan (1951). Coconut kernel and other nuts gave the following digestibility coefficients :—

Litchi nuts	81·82
Peanuts	81·85
English walnuts	83·00
Pecan	83·84
Almond	84·82
Coconut	87·89
Brazil nuts	88·00
Peanut paste	90·92
Pecan paste	81·83

Joachim (1924) found that pigs, horse and poultry fared well with a diet of coconut oil-cake. Similar views have been reported by Edwards (1924), Gallardo (1930) and others. Joachim also reported that coconut oil-cake fed to dairy cows increased the fat content of milk, retarded the natural decrease in milk yield due to advancing lactation and produced a hard butter of excellent flavour. The effects of increased milk yields, etc., are probably due to the fact that lauro-myristins present in quantity in coconut fat (oil) may have passed directly into the milk fat as found by Hilditch and Sleightholme (1938) in their experiments on cows fed with coconut oil-cake. Kuppuswamy (1946) has shown that coconut oil-cake can supplement the rice diet.

Carbohydrates

According to Caray (1921), dried copra meal contains the following carbohydrates :—

Sucrose	14·33	per cent
Raffinose	2·42	,,
Galactose	2·42	,,
Glucose	1·19	,,
Fructose	1·20	,,
Pentoses	2·40	,,
Cellulose	15·55	,,
Pentosans	2·22	,,
Starch	0·87	,,
Dextrin	0·58	,,
Galactan	0·50	,,

Cooke (1951) found 7, 16 and 3 per cent of sugar in fresh kernel, sweet toddy and tender coconut water respectively. Norris *et al.* (1922) have reported 15 per cent of sucrose and one per cent of glucose in fresh sweet toddy. According to Chandrasena (1930), the haustorium contains 9·49 per cent pentosans and 27·0 per cent lignin but that the kernel contains mainly cellulose. The cellulose was reported by Child (1939 *a*) and Cooke (1951) to be mostly digestible. Child (1939 *a*) also found coconut milk to be specially rich in digestible carbohydrates as most of the undigestible fibrous material is removed during the process of preparing the milk.

Minerals

Coconut is a poor source of minerals. The minerals of coconut kernel (*Wealth of India Raw Materials* 1950) are :—

Calcium	0·01 mgm per cent
Phosphorus	0·24 ,,
Iron	1·70 ,,
Copper	0·32 ,,
Sulphur	0·44 ,,

Vitamins

Coconut is not a good source of vitamins. A water soluble vitamin in coconut oil-cake and fat soluble vitamins A and E in coconut oil have been reported by Child (1939 *a*). Ghose (1922) found vitamins A and E in coconut oil but is of the opinion that vitamins are not likely to be present in the refined oil. Ray (1933) found vitamins A and B in the ripe kernel while the *Wealth of India Raw Materials* (1950) reports traces of vitamin A, 15 I.U. of vitamin B, 1·0 mgm of vitamin C and 0·2 mgm of vitamin E per 100 gm of the kernel.

Biswas and Ghosh (1936) have shown that vitamin C content in coconut water is richest in the green nut with soft pulp, gradually diminishing with ripening. According to them, vitamin C is at its maximum in the germinated fruit. Banerji (1935) found vitamin C content of green coconut kernel to be 0·2 mg to 0·4 mg/g as well as a thermolabile protective agent for vitamin C present in the water. Fair amounts of vitamins B_1, B_2, A and C are present in sweet toddy and coconut jaggery (Gopalan 1951).

Proximate composition

The proximate composition of coconut products is presented in the following table.

Table 57.—Proximate composition of coconut products

Head of analysis	Kernel of green coconut	Kernel of ripe coconut	Copra	Coconut oil-cake			Tender coconut water	Coconut milk*	Sweet toddy
				Mill	Expeller	*Chekku (ghanni)*			
Authority	*(Adriano, 1951)*	*(Wealth of India, 1950-IIC)*	*(Child, 1939 a)*	*(Wealth of India, 1950-IIC)*	*(Wealth of India, 1950-IIC)*	*(Wealth of India, 1950-IIC)*	*(Wealth of India, 1950-IIC)*	*(Child, 1939 a)*	*(Patel, 1938)*
Moisture	75·92	36·30	6·80	11·00	10·00	13·30	95·50	52·00	84·42
Ash (minerals) ..	0·98	1·00	2·00	5·70	5·30	4·00	0·40	1·10	0·26
Ether extractives ..	6·43	41·60	63·70	6·00	10·00	26·70	0·10	27·00	0·04
Proteins	9·41	4·50	7·60	19·80	19·10	14·30	0·10	4·00	0·12
Fibre	2·50	3·60	3·80	12·20	11·80	8·90	..	..	..
Carbohydrates ..	4·76	13·00	16·10	45·30	43·80	32·80	4·00	15·90	15·16
		Verghese (1952)							
Calories per 100 gm	123·92	448·90	675·70	334·20	360·70	443·00	17·40	326·60	61·60
Nutritive ratio ..	1 : 2·04	1 : 23·69	1 : 20·95	1 : 2·97	1 : 3·47	1 : 6·55	1 : 42·25	1 : 19·16	1 : 126·09

* The emulsion obtained by kneading and pressing fresh scraped coconut meat with water.

It will be seen from the above discussion that coconut products are valuable articles of food. Coconut oil is a valuable, edible oil high in nutritive value and digestibility. The coconut oil-cake is rich in proteins and furnishes essential amino-acids necessary for growth at almost normal rate. *The coconut oil is readily the coconut growers' greatest contribution to human nutrition and well being and the coconut oil-cake to the maintenance of animal health.* The kernel contains about 16 per cent of carbohydrates most of which are digestible and fresh sweet toddy gives about 15 per cent of sugars. The coconut, however, is a poor source of minerals and vitamins.

HUSK

The edible kernel of the coconut fruit is encased within a hard shell and outside this shell is a thick fibrous covering of husk. The most important commercial utilisation of husk is for the manufacture of coconut coir. Husks are also utilised as fuel, as a surface and seedling pit mulch and also for burying in coconut gardens.

Fibre-manufacturing process

Retting.—The indigenous methods of retting practised in India, although differing in detail, essentially consist of soaking the husks in water for a certain period. A common method (Fig. ***140***) is to soak the husks in basin-shaped pits. The pits are dug so as to be within the reach of gentle tidal action of the backwater waves; alternately, they are provided with channels to allow water to flow in and out with the rise and fall of the tide. Ordinarily, the bottom of the pit is sandy. Otherwise a layer of sand is placed at the bottom and the sides of the pit are lined with coconut leaves. After the husks have been filled in, they are covered with coconut leaves and mud and weighted down with mud to prevent floatation when water is admitted.

Another method which is in vogue in the Anjengo area in Travancore-Cochin and in Ponnani area in Malabar is to place the husks in coir nets. These are kept floating in the backwaters for a few days and then covered with coconut leaves and weighted down with mud so as to gradually sink under water. These bundles of husks are known as *Kollis* or *Mallis*.

A third method is to prepare enclosures in shallow backwaters with stakes and coconut leaves and then put the husks inside these enclosures. The husks are then covered with coconut leaves and weighted down with mud.

The process of retting and the factors affecting retting have been the subject of study by several workers who have come to the conclusion that the disintegration of the matter binding the fibres, during the process of retting is brought about by the action of certain organisms and therefore the efficiency and period of retting depend upon the suitability of the water for the action of the organisms. Their experiments further show that the organisms can carry on their action in saline water as well as fresh water, but that the salt in the saline water prevents over fermentation without discolouring the fibre, that the temperature of the water influences the activity of the organisms and that the changing of the water sufficiently frequently is necessary to prevent the organisms being poisoned by the products of their action. These observations help to explain the differences in the quality and yield of fibre caused by variations in the conditions of retting such as the nature of the water, the season and the arrangement for keeping husks under water.

In the first place husks retted in saline backwaters yield stronger and better coloured fibre because the deleterious matter is continually removed by the constant tidal action. On the other hand, retting is quicker in fresh water but is generally incomplete and the fibre retains a certain amount of pith. When retting is done in stagnant water, the products of the action of the organisms remain in the water and the fibre obtained is not only weak but also of dull colour. Secondly, as the influence of the cold water retards the activity of the organisms, retting is quicker in summer months. The colour of the fibre extracted in summer months is however brown owing to the increased concentration of salt in the water used for washing. Some salt also sticks to the fibre with the result that the yield is higher but the quality is poorer. When husks are soaked in shallow backwaters, the heating effect of the sun on the water helps to produce a better fibre. Thereby, the extent of the tidal action on the husks depends on the place where retting is done and the method of arrangement of the husks. For instance, when husks are placed in coir nets and sunk in backwaters, they are subject to better tidal action than when placed in pits.

Apart from these conditions under which retting is done, the time required for retting as well as the quality and yield of fibre also depend upon the condition of the husks used for retting. Fresh husks used within a few days of the husking of nuts are best suited for retting. Husks which have been exposed to the sun or are dry become brittle and do not yield good fibre. Besides, it is easier to beat retted fresh husks for the extraction of fibre. Generally, retting takes from six to twelve months depending on conditions.

It has also been found that the period of retting could be shortened by crushing the husks before soaking. The crushing could be done by simple crushing rollers similar to sugarcane crushers. If the husks are removed from the retting pits after they had been soaked for a month, crushed and then put back, the period of retting could be completed in three months. On the one hand, such crushing and handling of husks entail additional cost while on the other, the reduction in the period of retting has obvious advantages.

A smell of hydrogen sulphide is noticeable in the retting pits after about 30 days of keeping the husks under water ; the mass of husks becomes appreciably warmer, the water becomes more turbid and a scum forms on the surface. After about four to five months of soaking, gas formation, temperature, turbidity and smell increase. After six months the water becomes clear and the gas formation and smell diminish.

The possibility of producing sulphur from retting grounds has been examined by Warrier and Pandalai (1944) and they are of the opinion that the retting grounds would be a source of some quantity of sulphur.

Extraction of fibre.—After being taken out from the pits or *Kollis* or staked enclosures, the retted husks are washed with water to remove the adhering mud or slime and the outer skin is then peeled off. The washed husks are then placed on wooden blocks and beaten with wooden mallets to separate the fibre from the cork and pith (Fig. ***144***). The fibre may then be further cleaned by hand or washed a second time and then beaten lightly to separate the pith still adhering to the fibres. The wet fibres are then spread out to dry.

In the case of superior types of fibres, they are sometimes machine graded.

Chemical and mechanical methods of retting.—In all chemical methods of retting, the husks are at first split or crushed as much as possible. This is done by suitable machines or rollers. The crushed husks are then treated in different ways : (*Report Marketing, India,* 1943).

(*i*) *Nanji Process.*—In this process partially crushed green or dry husks are treated under pressure with sodium sulphate or sodium carbonate containing a trace of aluminium sulphate for a period of one to two hours whereby the fibre is loosened from the pith and separated by washing.

(*ii*) *Elod and Thomas Process.*—Here the fibre is separated by mechanical means after the crushed husks have been twice immersed in hot water, slaked lime or similar substances being added during the second immersion to avoid discolouration.

(*iii*) *Rowell Process.*—In this process the prepared material is subjected to a high steam pressure and the fibre comes out loose from the steaming chambers.

(*iv*) *Van der Jagt Process.*—Husks are opened in special machines, boiled with a weak solution of caustic soda and squeezed. The compressed fibres are then reopened, softened and cleaned. It is claimed that the fibre can be extracted in marketable form in less than two hours.

(*v*) *Hayes-Gratze Process.*—Husks, after being split into sections by special cutting machines, are immersed in water, pressed or rolled and then boiled in a solution of water and H. G. ionised oil. Coconut oil can be used for the preparation of ionised oil.

In addition to the above, retting processes making use of enzymes and bacteria have also been reported (Baruah and Baruah, 1946).

The main advantages claimed for the chemical process are the saving in time, a higher yield and greater uniformity in quality of the products in addition to the fact that the process can be used in areas where retting in backwaters is not possible.

In upland areas where facilities for retting as described above are not available, the husks are sometimes soaked in water for periods varying from a few hours to two weeks and the fibre extracted by beating as in the case of retted husks.

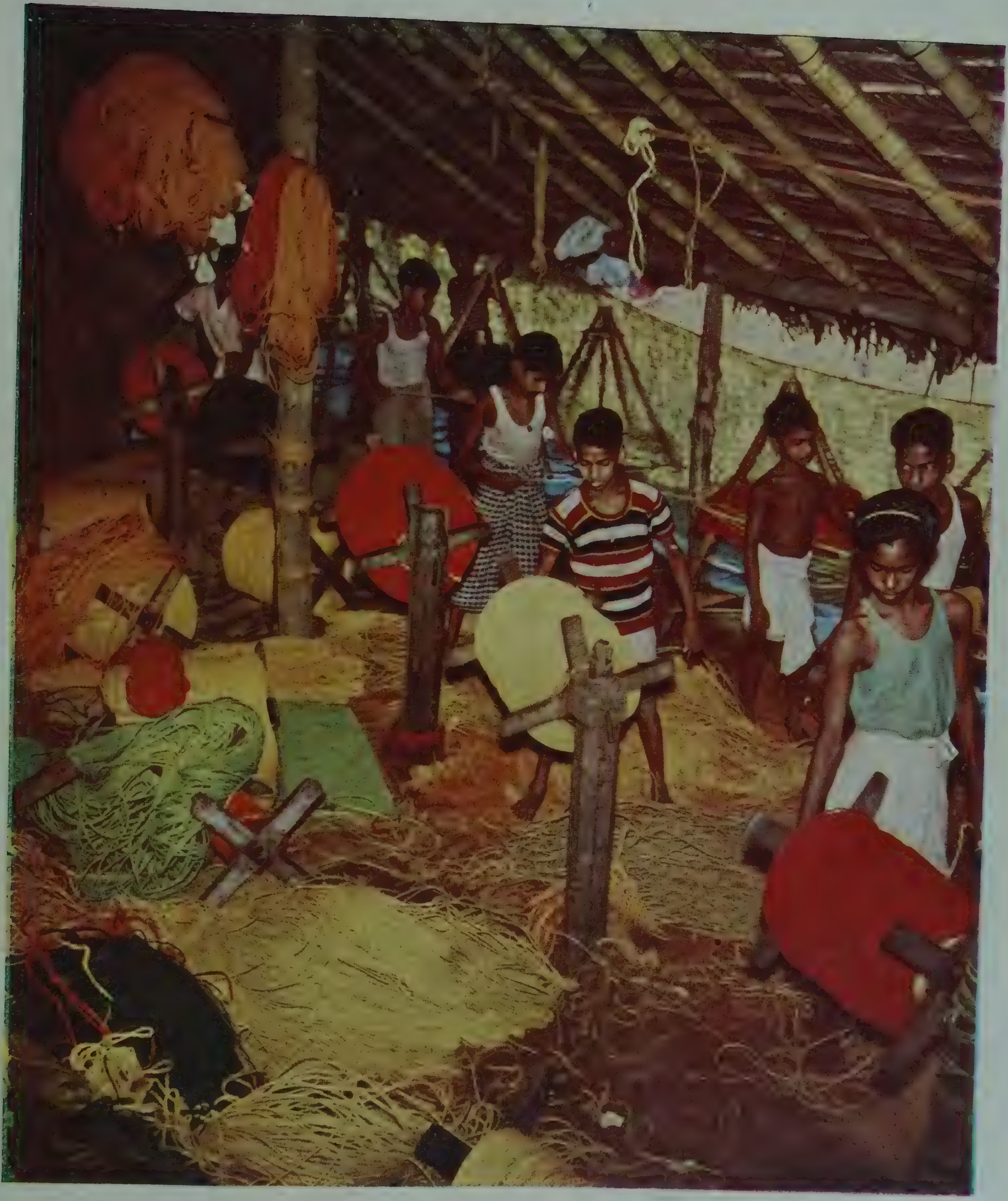

Fig. 145. Spooling of coir yarn (*Courtesy:* Coir Board, India)

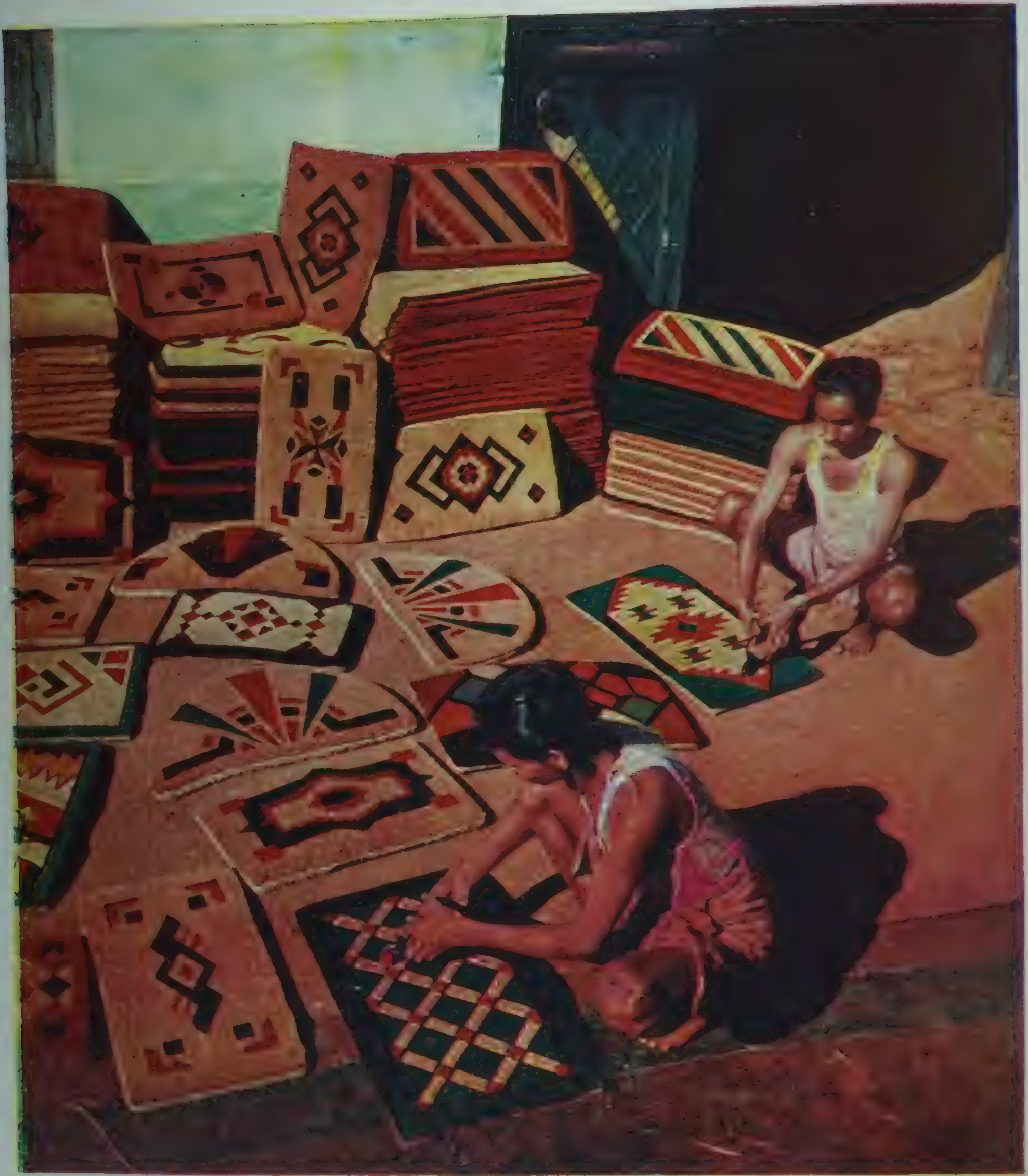

Fig. 146. Shearing of inlaid coir fibre mats
(*Courtesy:* Coir Board, India)

Sometimes, the husks are beaten with iron moulds driven by human or mechanical power. The beaten husks are torn on rolling cylinders with nails on the cylinder casing. The raw fibre thus obtained is further cleaned by means of blowing fans. A 100 kg hydraulic press helps to press the selected fibre.

Grading of fibre

The various types of fibres are broadly classified on the basis of practical experience. The best coir fibre without any pith on it is usually termed " Cochin fibre " or " Ceylon fibre ". Next comes the lustrous coir fibre, then the slightly reddish or greyish fibre containing some pith and lastly the inferior quality fibre mostly dark in colour and containing more pith.

Yield

The yield of fibre depends on many factors such as retting conditions, season, locality, etc. Generally in India, husks from 1,000 coconuts yield about 82 kg of fibre.

Fibre mills

In certain places, extraction of fibre is done on a factory basis in fibre mills. The process followed in fibre mills in Ceylon, as reported by Nataraja (1949) and Hudson (1951) is as follows:

Retting

This consists essentially of soaking the husks in water so that the fibrous and inter-connective tissues can be separated. The larger and more modern mills have installed special crushing machinery consisting of a chute leading into a pair of rotating fluted iron rollers set just wide enough apart to grip the husk and so crack the exocarp without seriously damaging the fibrous matter. As a result of this treatment the retting time is considerably reduced.

The retting is carried out in almost any place where stagnant water is available, such as ponds, depressions in the ground, at river's edge, but most commonly in specially dug pits and in the more modern mills in well-built concrete tanks. There is some retting in brackish water, but as far as the bristle and mattress fibre industry is concerned, it is confined to certain areas having lagoons, small brackish rivers and canals.

Pits vary in size and shape; at the average mills there are two, each approximately 23 m square, with a capacity ranging between 100,000 to 200,000 husks. There are larger pits with a capacity of up to one million husks but these are rare and only occur at the large mills.

Concrete retting tanks are expensive and therefore comparatively rare, but they offer certain definite advantages over pits, both as regards retting efficiency and the quality of the product. They are usually built as a series of small units each measuring approximately 8·1 m by 2·7 m and about 1·8 m deep. Their construction permits frequent changing of water which is free from mud and thus a superior quality fibre should result. Large concrete tanks about 23 m square are also found. The total capacity of the tanks at the large mills is 200,000 crushed husks or 140,000 normal husks.

Retting efficiency of pits depends to some extent on the quantity of husks, since there is no means of applying pressure to ensure the complete submersion of the husks, except that provided by the husks themselves. In the case of tanks, pressure is supplied by means of girders fixed firmly in the walls of the tanks just below the water level or in some cases by means of heavy logs placed on top of the husks and held in position by chains.

One big advantage of the tank over the pit is the time taken for retting. In tanks, retting of husks previously crushed is complete in three to seven days and if the husks have not had prior treatment, in seven to ten days. In the pits the period is much longer, ranging between three to six weeks according to the position of the husks in the pit, those which are completely submerged requiring a shorter period than those on the surface.

Fibre retted in tanks is better in colour than that retted in pits except when the latter have sand or gravel bottoms. It is possible for over-retting to occur, especially when due to shortage of work, the mills close down. The fibre obtained from these husks is poor in colour and lacks strength.

The retted husks are removed from the retting pits and tanks by boys who enter the water and throw out the husks which they consider are ready for separation of fibre. In large pits and tanks, a lane is marked out by bamboo canes and this area is completely cleared. The top husks which require further retting are thrown into the part of the pit just previously cleared. In the small tanks one unit is completely emptied at one time and the few husks which require further retting are thrown into an adjacent tank which is in the process of being refilled.

The retted husks are carried from the pits to the drums ; in large mills bullock carts are used, while in some cases trucks on a railed track carry out this function.

Decortication or milling

This involves the separation of fibre from connective tissues of the husks and is carried out by means of specially constructed machines called ' drums '. They are arranged in pairs, one is called the breaker drum and the other the cleaning drum. Each consists of a wooden wheel 0·9 m in diameter with treads about 0·3 m wide and 15 cm long into which have been bolted iron nails. In the breaker drum, the nails are bolted 3·8 cm to 5·1 cm apart, while the cleaning drum contains thinner nails placed 2·5 cm to 3·8 cm apart. The two drums contain a total of 1,200 and 1,350 nails respectively. The drums revolve at a high speed driven by a belt from a shaft which derives its power from a Diesel engine.

The major part of the wheel is enclosed in a wooden guard, but there is an opening about 0·3 m wide protected by a pair of rotating iron bars, the ends of which lie in grooves, which permit the upper bar to move up and down. This arrangement facilitates feeding and provides protection for the hands of the operator. The lower part of the covering of the wheel takes the form of a chute which delivers the material, removed by the nails on the wheel on to the ground below and well clear of the drum. Nails on the drums are subject to wear and tear and are normally replaced at least once every two months as worn nails tend to split and damage the bristle fibre.

Operators must be experienced and skilful if the best quality fibre is to be obtained and excessive waste avoided. The operator in charge of the breaker drum has the more difficult task. He holds one end of a piece of husk and forces the other end between the two iron bars so that the exocarp surface is pressed against the nailed surface of the rotating wheel. The nails tear away the exocarp, short fibres and connective tissue leaving the longer fibres. The operator then withdraws the husk and reverses it, repeating his previous performance so that eventually only the long fibres and some pith remain in his hands.

He places this fibre on a special ledge between himself and his fellow operator on the cleaning drum. This operator then takes three or four of these bundles of fibre and subjects them to a further cleaning treatment following the same procedure as before, pressing first one end and then the other against the finer nails on the cleaning drum. The fibre left in his hands is bristle fibre and the majority of it must be at least 20 cm in length ; otherwise it cannot be classified as such. About five per cent of the pieces of husk bought by the miller are below 20 cm long and these are used to supplement the mattress fibre.

The fibrous material removed by the breaker drum is subjected to a further cleaning process and is classified as mattress fibre. The fibre extracted by the cleaning drum is long in staple and usually more free from pith than the mattress fibre ; it is commonly called Mill O'Mat and is used by the miller for making the coir twine which is tied round the ballots of mattress fibre and bundles of bristle fibre produced at the mill.

It is generally accepted that one pair of drums can handle 2,000 husks during the course of a working day of eight hours. Out of 1,000 husks, on an average 51 kg of bristle and 102 kg of mattress fibre could be obtained, the outturn of the two types of fibre being normally in the ratio of 1 : 2. Small mills have three or four pairs of drums and the daily output is 306 kg to 408 kg of bristle fibre and 612 kg to 816 kg of mattress fibre. Larger mills have five to six pairs of drums, but up to 25 pairs are used in some mills.

Cleaning, drying and packing

Bristle fibre

The bristle fibre is conveyed by hand to a washing shed where it is rinsed by women in clean fresh water contained in a concrete bath about 3·7 m long, 1·2 m wide and 0·5 m deep ; this removes much of the mud and pith adhering to the fibre. Small bunches of washed fibre are then spread out fanwise on the ground for drying which is normally completed in about eight hours. The dried fibre is then collected and taken to the hackling shed.

Hackling is carried out by women and consists of combing the dried bristle fibre by drawing it through a set of steel spikes usually eight in number, each about 15 cm high, 2·5 cm apart, and fixed vertically on a table. This removes a further quantity of pith and the shorter fibres; the resulting product is called rough hackled bristle fibre. It is tied into hanks each weighing about 0·45 kg. 25 to 30 hanks tied together make a bundle ready for transport to the shippers' stores.

Many of the smaller mills do not hackle their bristle fibre and it is offered to the shippers as unhackled one-tie bristle fibre which is the lowest grade in the trade.

Mattress fibre

The fibrous material, pith and hard pieces of exocarp removed by the crushing drum, is carried by boys to a rotating cone-shaped sifting machine of stout wire netting with a mesh of about 3·8 cm, rotating at a speed which causes the fibres and other materials put in the narrow end to be subjected to a rough sieving action as they pass along the cone. Some short fibres, much of the pithy matter, and mud particles thereby removed collect underneath this machine, while the sifted fibre is discharged from the wide end of the cone. It is usual to put the short fibres and pith through the sifter a second time before they are removed.

When the fibre has been sufficiently cleaned in this manner, it is put into the ' teaser '. The ' teaser ' is a rectangular box, the bottom of which is wire-meshed, while all the other sides except one of the smaller sides are panelled with wood. The fibre is introduced into the ' teaser ' through an opening about 0·3 m square on the top and is subjected to a vigorous mechanical beating, thus separating from it whatever vegetable matter, etc. may still be adhering to it.

The thoroughly cleaned fibre is spread out on the ground to a depth of 0·3 m to 0·5 m to dry. In fine sunny weather, this is completed in about eight hours and the dried fibre is then taken to the baling shed. To ensure that the fibre is properly dried it is turned two or three times during drying by boys who flick the fibre by means of a forked stick.

In the baling shed, the fibre is packed by hand-operated presses into small bales, known as ballots, each containing approximately 5 kg of fibre. These presses consist essentially of two containers between which is an enclosed wooden ram used to compress the fibre into ballots measuring approximately 60 cm by 36 cm by 18 cm. The ram is moved on a ratchet by means of handles on each side of the press on which the packer swings with his hands and feet to exert the necessary pressure. Three boys are usually employed to pack the fibre, one supplies the material while the other two, working on opposite sides of the press, fill the box and move the ram into position in turns. The compressed fibre is tied with coir twine, passed through slots of the baling box, and then round the bale with the aid of a large needle. The ballot is now ready for delivery to the shippers' stores.

At the shippers' stores

Bristle fibre

The bristle fibre is weighed on arrival and samples drawn from the bulk delivery for examination as a result of which the fibre is graded and a price fixed. Grading points are length, stiffness and colour. The lowest quality usually receives no further attention except bleaching. The better qualities after storage to ensure complete dryness are hackled in the same manner as at the mills, but with a greater thoroughness, an oily liquid, chiefly coconut oil, being used on the hackling pins.

The fibre is then graded as regards length and converted into hanks each weighing about 0·5 kg and tied by three, two or one twisted fibre cords, according to grade. This fibre is then bleached to obtain a more even colour. Bleaching is carried out in sealed rooms with slatted floors under which run tunnels in which pans containing burning sulphur are placed; the sulphur dioxide bleaches the fibre. Bleaching occupies approximately 24 hours, and the bristle fibre should then be of a uniform golden colour. Two other processes are carried out on occasions at the shippers' stores, namely, dyeing and drafting.

The dye, normally black in colour, is contained in large metal vats with open tops. The fibre is introduced into the dye in a cage lowered into the vat by a pulley. After being withdrawn from the vat the fibre is left in the cage to drain and then dried in special ovens.

Drafting is really a form of super-hackling and grading according to fibre length. The resulting hanks are cut to a given length and the product is ready for immediate use.

The hanks of bristle fibre are baled under pressure and the baling box is lined with hessian so that the resulting bale is completely protected. The baling presses are of the hydraulic ram type, but the pressure is closely controlled as excessive compression damages the fibre. The recognised market grades for unbleached bristle fibre are three tie, the longest and best quality ; two tie, average in length and quality ; one tie, rather below average in length and quality and one tie unhackled, which is variable.

Mattress fibre

The ballots are weighed and a few samples drawn for inspection. The fibre is graded ; grading is based on colour, fibre length, resilience and general cleanliness, especially the quantity of pith present. Three classes are generally recognised. The best grade mattress fibre known as " No. 1 " in the trade is of a fine golden colour. The next grade known as " Fair Average Quality " or " F.A.Q." is duller in colour and has less ' life ' in it, while the lowest grade known as " No. 2 " is dark in colour.

After grading, the fibre is stacked in storage sheds, in ballot form, up to a height of 9 m to 12 m. The fibre remains in the store for at least three weeks before it is baled prior to shipment. The shipper prefers to bale fibre with a moisture content of 12 to 14 per cent.

The shippers usually have cleaning plant available, and this is used before the fibre is baled if necessary. Cleaning necessitates the breaking up of the fibre ballots and results in baling the fibre in its loose form. After cleaning, the fibre is weighed out in 51 kg lots and transferred to the baling shed. The ballots are sent direct from the stores and the coir twine removed before packing, but no weighing is necessary and filling in is done with the aid of a supply of loose fibre. In some cases ballots are opened and teased out by hand before the fibre is packed into the baling box.

Baling presses vary in design, but the principle involved in each case is that of a hydraulic ram and there are generally two baling boxes. The older type of press has baling boxes which are filled by hand and the fibre is pressed into space by a boy standing in the box and stamping down the material with his feet. Ballots are often used for this type of baling as they are already compressed to some extent. The new type of baling press is fitted with a rammer which operates from above the box and is more effective in compressing the fibre, particularly during the initial stages.

When full, the baling box is swung into position above the hydraulic ram and the reserve box is then ready for filling. The ram is brought into action ; the doors of the baling box are opened, and the hessian squares placed in position. The baling iron is tightened round the bale with a special grip, which has a long handle for leverage purposes. The iron is held in position by wooden chucks until it is eventually tied and the pressure released.

The 153 kg bale which is the one now generally supplied, varies in capacity from 0·28 cubic metre to 0·34 cubic metre. Mattress fibre can still be obtained in the twisted rope form, but the demand for this material is very small. It is claimed that the product is more resilient than the material in baled form.

COIR PRODUCTS—MANUFACTURE

Coir yarn

Coir yarn is prepared by spinning the coir fibre.

Hand spinning

The usual practice in hand spinning is to roll the fibre into short lengths of 15 cm to 23 cm giving a clockwise twist by hand. When a sufficient quantity has been made, two of these short lengths are taken in hand together and made into yarn of two plys by giving a counter-twist using both palms. When the counter-twist reaches the end of the string, further pieces of short lengths kept ready are added one after the other, while counter-twist by hand is continued till the required length of yarn for a knot is reached. When the required length of about 6 m to 18 m is reached, the yarn is reeled in the form of a ' hank ' and a knot is made at the end. Hand-spun yarn always has a soft twist.

Wheel spinning

To prepare two-ply coir yarn on the spinning wheels, one set of two wheels, one stationary (Fig. *141*) and the other movable (Fig. *142*), is required. The stationary wheel contains two spindles set in motion through the central wheel. A handle for turning it is inserted through the centre of the wheel. The movable wheel contains one spindle only and is mounted on three wheels so that it can be moved forwards and backwards. Shivers of coir fibre are taken by two persons, usually women, who, keeping them in their arm pits, make a loop with a small quantity of fibre. Each then puts the loop thus made into the notch of one of the spindles on the stationary wheel and gives the fibre a uniform thickness. A third worker now rotates the wheel and gives the twist to the fibre. As the wheel is being rotated, the two spinners deliver fibre in required thickness, walking backwards till the required length of strand is reached. The two strands thus made are passed through a grooved rod and tied together to the notch of the spindle of the movable wheel. The movable wheel is then rotated in the opposite direction and one of the spinners moves with the grooved rod towards the stationary wheel. As the wheels rotate, the two strands of yarn are twisted together. The object of the grooved rod is to regulate the twist of the yarn and to prevent entanglement of the strands at the time of twisting.

When the length to be twisted becomes shorter, the movable wheel is turned towards the stationary wheel for a short distance. By now, the grooved rod would have reached the stationary wheel. The turning of the wheels is now stopped and the movable wheel taken back to its original place. All the ends from the stationary wheel are then cut off and the yarn is tested for sufficiency of twist. The yarn is then reeled into the form of hanks of usually 15 m to 18 m length. Three persons working a set of wheels produce on an average from 5 kg to 15 kg yarn per day.

Grading

Just as in the case of fibre, the main characteristics which make up for quality in coir yarn are cleanliness from pith and impurities, evenness of twist, colour, etc. The main descriptions of coir yarn are based on the names of the localities where they are produced, as each locality seems to have developed special skill and processes and those therefore, give the yarn produced certain special characteristics. Sixteen such varieties or grades have been recognised in India (*Rep. Coir Board,* 1955 *c*). Some of the more important grades are illustrated in Fig. ***143.***

Coir rope.—Rope making is done on a pair of rope making machines which are similar to the spinning wheels described above except that the stationary wheel contains two or more hooks geared together.

To make strong ropes, a number of thin yarn strings of the required thickness are cut into equal lengths as per the required strands of the ropes. The ends of all these strands are tied to individual hooks on the stationary wheel and all the other ends are passed through the grooved rod and then tied to one hook on the movable wheel. A new twist is given to the individual strands by turning the handle of the stationary wheel. When sufficient twist is imparted to the individual strands, the movable wheel is turned in the opposite direction and the grooved rod moved forward till it reaches the stationary wheel. The strands are then removed from the hooks and a knot is made after the grooved rod is taken away. The rope is then coiled and packed for despatch to marketing centres.

Coir mattings, carpets, brush mats and fibre mats.—An account of the manufacture of these products according to *U.N.O. pbl.* (1954) is given below.

Matting

Coir mattings are woven on looms similar to the ones used in cotton weaving. But the framework, sley, reed, healds, etc. are much stronger than those used in cotton weaving. Warp of coir yarn is beamed as in the case of sectional warping method adopted in cotton weaving and is taken to the loom where the warp ends are drawn through the healds and the dents of the reed and weaving started. Spooling of coir yarn is shown in Fig. ***145.***

The weaving of mattings is just like the weaving of other fabrics. Patterns up to eight treadles are usually woven on the ordinary looms and for designs beyond eight treadles, Jacquard Machines are used. The Jacquard Machine for coir industry has the same working mechanism as the ones used in cotton textiles. But the machines are made stronger to withstand the strain during weaving operations.

The operation of weaving is similar to pit-loom weaving without fly-shuttle arrangements. For close weave, a stick is inserted through every shed and used as a beater before the weft is passed through the shed. After the weft has been passed through the shed, the stick is removed and the sley is well beaten up before the shed is changed. The process is repeated till the required length is woven. When the required length of 45 m is woven, the matting is removed from the loom and mending is done. The main mending work is to eliminate the knots which sometimes project out of the matting, to remove the uneven coloured yarn and to cut away the projected warp or weft ends on the mattings. After the mending work has been completed, the mattings are rolled into bundles of 45 m length. In some cases, where there are bucklings (uneven tension), the mattings are stretched on a stretching machine before being rolled.

Carpets

Coir carpets are woven on ordinary coir matting looms. The design is effected by inserting the coloured weft yarn. The rest of the process is just the same as in the weaving of coir mattings. In mattings, the designs are obtained with the effect of the warp ends while in the case of carpets, the designs are obtained by weft yarn. Any pleasing colour can be given.

Brush mats

The warp ends are first prepared and drawn in through the heald shaft and then on to the reed and the operation is started as in mat weaving. Now three or four strands of yarn are inserted through the shed and are taken out of every alternate warp ends and wound on a grooved iron rod placed over the warp ends across the mat. Then, after a single weft has been inserted through the same shed, the sley is beaten fast to allow the weft to get close to the fabric. After changing of the shed by treading, a knife is passed through the groove of the iron rod facing upwards and the end of the rod is cut off. The process is repeated till the required length is obtained. When the required length is obtained, three or four weft yarn are woven to make sure that none of the piles gets out of the mats after removal from the loom. The mat is then stitched with a coir braid all round and is trimmed (Fig. *146*). These mats are often stencilled with attractive designs. The cheapest variety of mats is usually made by this process.

Fibre mats

There are two varieties of coir fibre mats which are made on looms as well as on small door frames. In either case, the warp yarn is to be prepared first. The process of weaving is more or less the same as for woollen carpet weaving. The piles of fibre are inserted by hand into the warp according to the design, one by one, and when the fibre has been inserted to all the alternate warp ends, a weft yarn is inserted through the same shed and the sley is attached to the fabric already woven. Now the fibre is cut to the required height. Then the fibre is inserted to the other alternate ends as before. For designed mats, coloured coir fibre is inserted according to the design. When the mat is removed from the loom, a braid is stitched all round the mat and is trimmed on a shearing machine as in the case of brush mats.

In the case of fancy fibre mat, the warp strands are grouped by three. Every alternate end is from loose warp forming the back surface and the other ends are grouped by two and the fibre is inserted in-between. After three or four weft yarns have been woven, the fibre is inserted to one of the groups of the warp and two weft yarns are woven, one by lifting all the alternate loose warp-ends and the other by lifting all the tight warp-ends. The same process is repeated till the required length is reached. Very attractive designs are effected on the fancy fibre mats.

When the mat is completed, the warp ends at either end are drawn in and the mat is trimmed on a shearing machine as in the case of brush mats.

Coir mats, mattings, rugs, carpets, etc., of a wide range of qualities and attractive colours and designs (Fig. *147*) are very well-known throughout the world for durability, sound-proofing and damp-proofing qualities and are largely used for floor covering in offices, factories and residential places.

Felt (Hard board). Coir fibre of inferior quality may be used for manufacturing hard board. Ordinarily, low grade coir fibre (100 kg) is mixed with fossil resin (10 kg) melted at a high temperature and suitably pressed into boards of suitable size. A rolling mixer may be used to integrate the fibre with melted resin and a hydraulic press to press the mixture into hard board.

It is also possible to press loosened fibre into hard board type of felt without mixing resin. Low grade hard board can also be made from ' fresh wet husk '. By means of its own gum, pressed with a hydraulic press at a pressure of 10·5 kg per sq cm the coir fibre is well bound and made into a strong useful board. Old or retted husks can also be utilised for the purpose.

To make hard board of standard quality, however, suitable machinery is required. A process for preparing hard board (wall board) from coconut husk-shorts and coir dust has been described by Hume (1949) and coir boards can be produced by this process in any thickness without lamination. The boards are durable, smooth on both sides, inherently insect proof, fire retarding and water-repellent. They may be sawed, nailed, glued and finished into any type of board according to requirements.

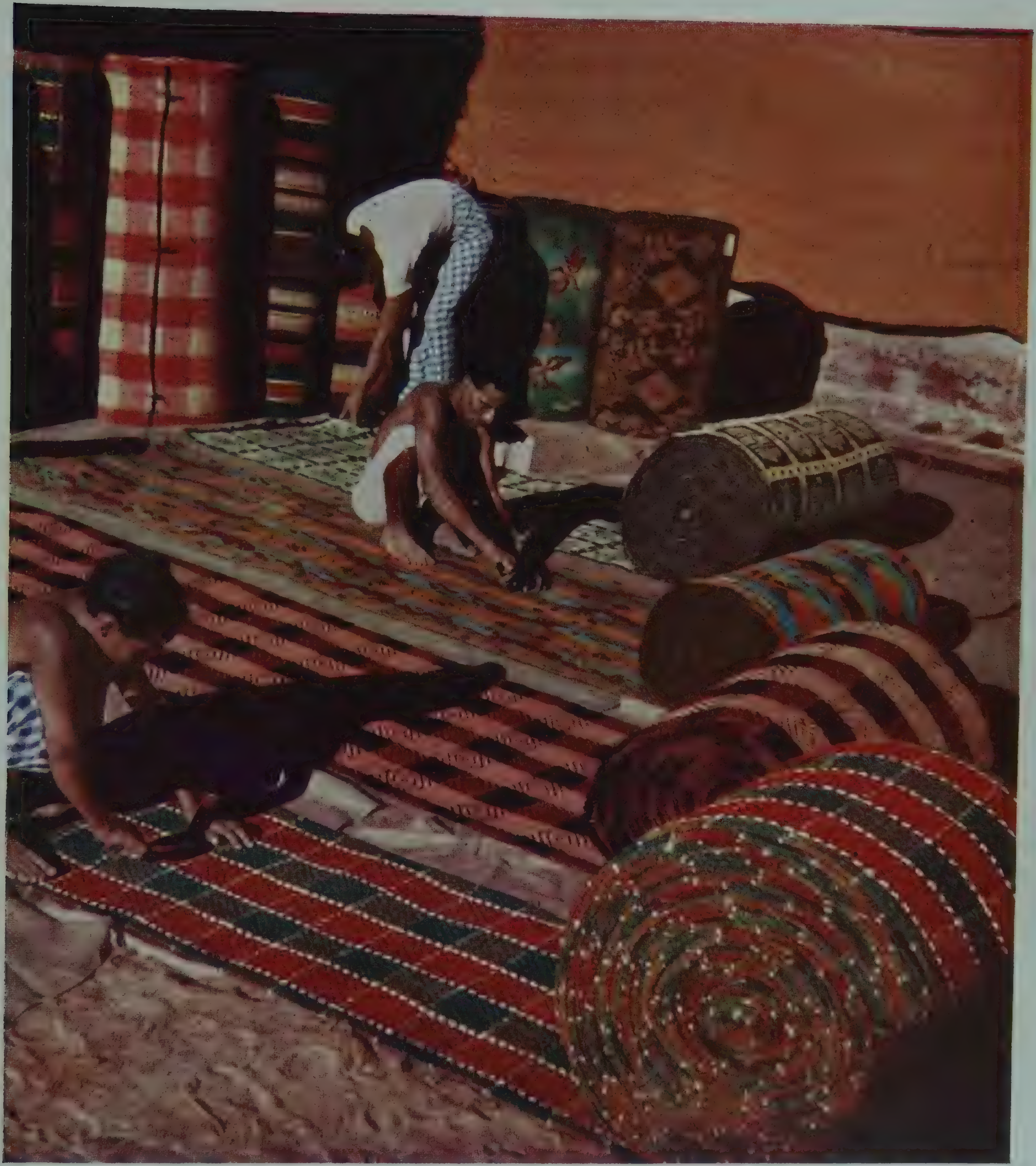

Fig. 147. Passing of coir mattings for shipment
(*Courtesy:* Coir Board, India)

Fig. 148. Coconut Shell

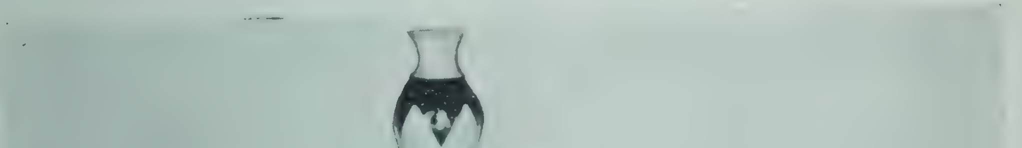

Fig. 149. Shell products

Coir dust. Coir dust is the pith and cork left over after extraction of fibre from coconut husk. It can hold eight times its weight of water and is therefore an excellent mulching material for nurseries. It has been reported to be of great use as a rooting medium and insulating material, also as a soil conditioning medium (Hume, 1949). It has but little manurial value.

Pillai and Warrier (1952) have reported the following chemical composition of coconut pith :—

Moisture on air dry sample (dried at 105°C)	11·9	per cent
Ash (on material dried at 105°C)	8·7	„
Fats and resins	1·8	„
Cellulose (Chlorine method)	35·0	„
Lignin (by 72 per cent sulphuric acid method)	25·2	„
Pentosans	7·45	„
Loss on boiling with 1 per cent NaOH for 5 minutes	12·00	„

Coir dust has also been found to provide base material which can be used in a variety of ways such as the manufacture of travelling cases, boxes, hard boards for screens, etc.

Production

Authentic statistics relating to the production of coir fibre, coir yarn and other products are not available. Although India's total production of coconuts is estimated at approximately 415 crores, only about 162 crores husks are actually used for the coir industry with the production of 132,080 metric tons of coir fibre. The manufacture of coir yarn has been computed at 121,920 metric tons (*Rep. Coir Board* 1955 *a*, *b*). The other important producing country is Ceylon. The total output of the coir fibre of Ceylon entering the world's markets was approximately 69,900 metric tons (15,240 metric tons as bristle fibre and 54,660 metric tons as mattress fibre) and 2,662 metric tons of coir yarn in 1954 (*Rep. Ceylon Chamber of Commerce*).

The following quantities of coir mats, mattings, rugs and carpets have been exported from India to various countries (*Rep. Coir Board* 1955 *d*).

1949–50	25,860	Metric tons
1950–51	23,120	„
1951–52	15,110	„
1952–53	18,510	„
1953–54	22,360	„

SHELLS

Coconut shells have always been used in the domestic economy of the coconut growing countries in a variety of ways.

Whole shells

(1) *Hookah shells. Hookah* (Hubble-bubble, an arrangement for smoking tobacco) shells are usually prepared by scooping out the kernel from husked nuts by means of special thin pointed knives through a hole bored through one of the eyes of the nuts. Usually oblong shaped nuts are selected for this purpose. The outside of this shell is well polished before use.

(2) *Shell bottles.* Bottles of whole shells are made in a similar way by simply boring a hole through one of the eyes and removing the meat or keeping it till the meat is rotted out and then it is like a bottle without a neck, used for keeping oil, liquor, etc.

Cups

Of the enormous quantities of shells produced annually in coconut producing countries, the bulk is used as fuel, both as domestic fuel and as fuel for copra kilns. It is also used as fuel in lime-kilns, brick-kilns, etc.

The shells are not however favoured as a boiler fuel. There seems to be a rapid corrosive effect of the vapours on fire-bars, etc., due partly to the high temperature reached and to the acid nature of the combustion products when air intake is insufficient.

Shell cups are also used for setting jaggery, for collecting rubber latex and as measures for many types of liquids.

Other uses

Coconut shell (Fig. *148*) is hard, takes a high polish, can be carved, decorated with lacquer, inlaid with silver or other metals and generally used with ornamental effect. Local craftsmanship has therefore produced articles of very attractive appearance and characteristic of the native art of the various countries of origin. Such articles include lamps, goblets, flower vases, combs, ladles, bowls, stands, buttons, cuff-links, ash trays, trinket-dishes, paper weights, tea sets, musical instruments, spoons, sugar pots, and bangles (Fig. *149*). But such articles are not prepared on any large scale.

Shell charcoal

A considerable portion of the available supplies of shells is used for preparing shell charcoal. Shell charcoal is prepared by burning the shells in a limited supply of air in suitable kilns (*Coconut Research Institute*, Ceylon, *leaflet* No. 6).

Quality

The following are the specifications prescribed for shell charcoal (*Rep. Marketing, India*, 1943), (*Coconut Research Institute*, Ceylon, *leaflet* No. 6).

1. *Moisture* not more than 10 per cent.
2. *Ash* not more than 2 per cent.
3. *Chloride* not more than 0·1 per cent.
4. *Volatile matter* not more than 15·0 per cent.
5. *Size* not more than 5 per cent, shall pass a 0·63 cm mesh sieve. Good charcoal should be uniformly black and free from dirt due to husk. Broken edges should show a shining black surface and a characteristic sharp fracture.

Uses

Shell charcoal is used in laundry, smithy, bakery, etc. Some quantity of charcoal is used in primitive copra kilns, in preference to coconut shell. Well powdered coconut shell charcoal finds a limited use as a dentifrice. The charcoal is used by goldsmiths in melting gold and silver and for other metal work including brass. It is used extensively after further processing (activation) for making gas masks, activated carbon, etc.

Yield

About 7,000 whole shells go to make a ton. The yield of charcoal is roughly 30 per cent of this. Nearly 70 per cent of the shell which contains some valuable constituents are therefore wasted in the above process of preparing charcoal. Some of these constituents which are commercially important, can be recovered if, instead of burning in pits, the shells are fired in ovens or retorts heated from outside under controlled conditions.

Dry distillation of coconut shells

When heated in suitable stills, coconut shells undergo what is termed destructive distillation and gases begin to be given off at about 300°C. At about 600°C to 700°C the volatiles are completely driven off, though sometimes a maximum temperature of 900°C may be reached in the stills. The gases that come off are condensed, the non-condensible portion being scrubbed and used in suitable burners for heating the stills. Such gases would be about 20 per cent of the shells by weight or about 170 cubic metres of gases of calorific value about 320 B.T.U. per 0·028 cubic metre.

The condensed or settled pyroligneous acid contains acetone (B.P. about 56°C), methanol (B.P. about 65°C), and acetic acid (B.P. about 118°C); carbolic acid, creosote, pitch, etc., are recovered from the settled tar.

The carbonised shells or ' char ' from the first still is given suitable treatment with steam and acid and standardised. The ' char ' is then powdered in a closed grinding circuit with air separation system, bagged and sold as active carbon.

The various economic products that could be obtained from the dry distillation of the shells and further processing of the ' charred shell ' and the distillate are :—Shell charcoal, active carbon, acetic acid, methanol, acetone, methyl acetone, carbolic acid and pitch. Poti (1948) reports the yield of these products as follows :—

Charcoal	35	per cent
Acetic acid	6	,,
Methyl acetone	1·5	,,
Methanol	0·5	,,
Carbolic acid	0·6	,,
Creosote	0·5	,,
Pitch	10·0	,,

Similar results have been reported by Child (1939 *b*) and Jayadas and Warrier (1953).

Uses

The shell charcoal obtained in the above process is free from moisture and volatiles and can play a prominent part as fuel for automobile gas generators. The charcoal can be activated and the active carbon can be used for refining vegetable oils, sugar, glycerine and syrups, in the recovery of solvent vapours in water purification, etc.

The other products like acetic acid and acetone can also be put to many industrial uses.

The possibility of commercial production of furfural from coconut shells has been investigated by Harcharan Singh (1956). The shells are crushed, disintegrated to 20 mesh and ground in a stone mill to particles weighing 100 mg to 150 mg each. The ground material (40 kg) is digested for six hours with water (36 kg) and sulphuric acid of sp. gr. 1·64, (0·7 kg) maintaining a pressure of 5·6 kg and 4·6 kg per sq cm at the inlet and outlet respectively and the vapours suitably condensed. The yield of furfural is, however, low, the free furfural in the condensate being 0·86 per cent even though the shells contain as high as 21·10 per cent of pentosans. The residue left after extraction of furfural is found to be suitable as a filler for phenolic moulding compounds.

Shell ash. Figures ranging from 0·23 to 1·425 per cent of ash in coconut shells have been reported (Child, 1943 ; Tendolkar and Thakoor, 1952). The ash contains 30 to 45 per cent of K_2O. Shell ash has therefore some manurial value but it is rather difficult to obtain the ash in sufficient quantity for use as a potassic manure, about a million shells being required to produce one ton of ash. Use of shell ash in native medicine has also been reported.

In a series of articles, Child (1939 *b*, 1943, 1944, 1949 *a*, *b*, *c*) has dealt rather extensively with the different aspects of coconut shells as an industrial raw material.

Shell powder. It is also reported that shells are powdered and exported as shell powder.

Toddy. Tapping coconut trees for toddy has already been described. (Chapter XVII.)

Toddy ferments readily to give an intoxicating drink.

Sweet toddy (*Neera*). Sweet toddy (*Neera*) is unfermented toddy. The tapping for neera is done exactly as for extracting toddy. The tapper cuts the spathe of the palm both morning and evening and applies lime to the pot both times. But *Neera* is lowered only in the morning. *Neera* is free from alcohol as the lime prevents alcoholic fermentation. It is a sweet, refreshing and health-giving drink. But if left in the absence of sufficient lime, it becomes fermented easily and converted into toddy.

Jaggery *(gur)*. *Neera* when boiled to 118°C to 120°C and allowed to cool, solidifies. The solid mass is known as coconut jaggery or *gur*.

The crude way of making jaggery is to strain the *Neera* and boil it in tall mud pots, till it becomes viscous. The viscous mass is poured into coconut shells or other moulds where it solidifies. The jaggery made in this way is black in colour and has a caramalised taste. This is due to the presence of excess lime and uneven heating whereby some of the jaggery on the sides of the pot gets burnt.

Several improvements of the method have been reported. The procedure now adopted in India for producing *gur* is as follows :—

A shallow iron pan is used in the improved method. An improved furnace is also designed to economise fuel consumption.

The *Neera* is first strained through cheese cloth or wire net. Then the boiling pan is smeared with oil and slightly heated. The oiling of the pan checks caramalisation and lengthens the life of the pan. The filtered juice is poured into the pan and slightly heated. Superphosphate is then added in small quantities till the pH reaches about 7·0. This precipitates the excess lime. The *Neera* is then heated to about 70°C. After that, the juice is filtered through a piece of drill cloth. The filtered juice is again boiled in the pan. When the boiling starts, the froth comes upto the surface and is removed with a perforated ladle. The juice is stirred at intervals to facilitate rapid evaporation. Light fuel is advantageously used at this time. When the juice is turned into a viscous mass, firing is controlled. To test whether the juice has reached the 'gur' stage, a little quantity of the boiling mass is put in a cup of cold water. If it has reached the right consistency, it turns solid when rolled between the fingers. The viscous mass is then poured into suitable wooden moulds. After allowing the gur to set for some time, it is removed from the moulds and suitably packed. The gur so prepared, is hard, crystalline and golden in colour (*Palm Gur Adviser,* 1956).

Coconut jaggery is a sweetening agent and is used in the preparation of several dishes. This jaggery is even superior to cane jaggery.

Coconut palm sugar

Sugar can also be made from *Neera*. *Neera,* de-limed and clarified as above, is concentrated by heat in a shallow iron pan and when the temperature of the boiling liquid reaches 110°C, it is poured into a crystalliser. After 24 hours, sugar crystals are formed. The 'rab' is then centrifuged and separated into sugar and molasses.

Coconut palm candy

When the boiling point of the de-limed and clarified *Neera* reaches about 105°C, it is poured into an earthen pot. Sticks of *Karandi* (a kind of bush) or bamboo are placed in the earthern pot to serve as base, before pouring the 'rab' into it. The pot is then buried neck deep in the ground for two to four months. At the end of this period, the pot is taken out. Big crystals of palm candy will be seen clustering on the twigs of the bush. The candy is collected, washed and sundried.

Molasses

The preparation of aerated waters from molasses obtained while preparing coconut palm sugar has been reported.

Distilled liquors

Toddy contains about 18·5 per cent of total solids and 15 to 16 per cent of sugars almost all of which is fermentable. Fermentation of toddy is complete in about 24 hours in distilleries.

The following table as given by Nathanael (1956 *a*) gives the differences in average composition of fresh sap, fermented juice and stale toddy.

TABLE 58.—Composition of fresh sap, fermented juice and stale toddy.

	Sweet toddy (gm/100 ml)	Fermented toddy (gm/100 ml)	Stale toddy (typical) (gm/100 ml)
Total solids	18·7	4·5	4·4*
Acidity (as acetic)	trace	0·6	1·6
Alcohol (v/v)	nil	7·5	6·5
Ash	0·40	0·40	0·40
Sucrose	16·5	..	..

* Including any unfermented sucrose.

Two types of arrack known as Pot arrack and Patent arrack are usually prepared from fermented toddy.

The toddy as received is delivered to settling tanks, and then transferred to wash backs and then to the pot or patent still. Here the toddy is boiled and the vapour passed through rectifiers and condensers and finally collected in suitable receivers. Pot arrack is 18° to 20° U.P. while Patent arrack is 30° U.P. In the distilleries, the recovery of alcohol is about 7·5 per cent.

Vinegar

Vinegar is manufactured by acetic fermentation of dilute alcoholic liquors obtained from various carbohydrate materials. It is a very ancient industry. Several methods of slow as well as quick fermentation processes have been evolved. In coconut producing countries, it has been the practice to prepare coconut vinegar from fermented toddy.

According to Balakrishna Murthy (1951), toddy is allowed to ferment in acetifying vats of about 200 to 300 gallons capacity. When the vats are full, they are partially covered with wooden boards and jute hessian or sometimes with coconut leaves. Free access of air is necessary for acetification reactions. Original toddy contains about 16 per cent of sugars which by the first phase of fermentation is converted in about 24 hours to alcohol of about 7 per cent strength. The slower process of oxidative fermentation or acetification then sets in whereby the alcohol is converted into acetic acid. The vinegar contains 4 to 5 per cent of acetic acid. Acetification usually takes 10 to 14 weeks at the end of which time the scum of yeast and mould growth sinks to the bottom and the liquid appears clear.

The vinegar is then matured. It is transferred to casks in which maturing takes place. Flavour improves with time. Some manufacturers keep it upto six months.

Before bottling the vinegar, it is coloured usually with caramel.

Several ‘ quick ’ processes for obtaining good quality vinegar from coconut toddy in a short time have been reported. In this connection the work of the Coconut Research Institute, Ceylon, is extremely interesting (Nathanael, 1952, 1955 and 1956 *b*). Nathanael has evolved a new quick-generation process for making high grade commercial vinegar.

Uses.—Vinegar is extensively used for table purposes, for the manufacture of pickles and condiments and also to some extent in indigenous medicine.

Leaves

Coconut leaves are plaited and used for thatching houses, for covering retting pits, making partition walls in separating different lots of husks retted in linear trenches, for making baskets, etc. Experiments conducted at the Central Coconut Research Station, Kasaragod have shown that leaves soaked in saline water prior to plaiting withstands the combined action of wind, rain and sun better than the unsoaked leaves or leaves soaked in sweet water. Plaited leaves are also made into several types of head-gear and are worn by poor men and women while out in the field. Unplaited coconut leaves are also used for shading seedlings, mulching nursery beds and for fencing, etc. The dry leaflets are tied into small bundles and used in villages as country torch in the night.

Midribs of leaves. The midribs of leaves are utilised for making brooms, baskets, fish traps, etc.

Petioles, bunch stalks, spathes, stipules, etc. These are mostly used as fuel.

Trunk. The trunks of old coconut trees are utilised as timber for house-construction. The quality of the timber is improved if it is soaked in saline water for some time.

Edible parts. The apple or cotyledon developing during germination and the tender bud are delicacies. The tender husks of some varieties are edible and are sometimes pickled.

Coconuts and coconut products in medicine. Several coconut products and parts of the palm are used for medicinal purposes (Nadkarni, 1954).

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CHAPTER XVIII

CERTAIN PROBLEMS IN COCONUT RESEARCH

AGRICULTURAL AND TECHNOLOGICAL RESEARCH

In the preceding chapters, an attempt has been made to present the manifold aspects of recent research work on coconut carried out in the important coconut growing areas of the world. Although quite a good deal of useful information has accumulated, it would appear that our knowledge on several points is still inadequate. The need therefore of concerted and co-ordinated research on the different problems confronting the coconut grower is quite apparent. Some of the problems are regional while others have to be tackled on an international basis.

Research on coconut may be divided as agricultural and technological. Problems concerning agricultural research may be classed as those relating to all producing countries and those relating to particular regions. In the former category, perhaps the most important is the necessity to have a central clearing house for all information regarding coconut. Other subjects coming under this are the need for the institution and maintenance of a central collection of world varieties of coconut at some suitable centre, survey of world varieties, exploring the possibilities of the production of economic varieties, hybridisation, survey of the common pests and diseases of world importance and the statistical estimation of area and production of coconut in the important coconut growing countries. Investigations on the manurial requirements of coconuts, on cultural practices, on regional pests and regional diseases, etc., could be tackled better by the countries concerned.

Technological research problems are generally common for all coconut producing countries, since they relate to the proper utilisation of coconut by-products. A unified and co-ordinated research scheme for technological research on coconuts would be beneficial to all countries.

CENTRAL INFORMATION BUREAU

Despite the fact that research work on coconuts is being conducted in different places, information regarding the nature, and progress of such work is not readily available. Most of the research workers now appear to be working rather in isolation and a central pool for gathering and transmitting information would be a very welcome feature. A central information bureau should endeavour to collect, consolidate and disseminate all-round information for the producer, the consumer and the research worker.

CENTRAL COLLECTION OF WORLD VARIETIES

In this connection the following resolution passed by the Eighth Pacific Science Congress held in the Philippines (1953) is of considerable interest. " The Congress recommends that all coconut producing countries in the Pacific region co-operate and co-ordinate efforts to collect all the varieties or strains of coconuts found in their respective regions together with complete descriptive data of each variety ". The information that would be forthcoming when this resolution is implemented would be of great value in preparing an international key for the classification of coconut varieties. The maintenance of a comprehensive and representative central collection of world varieties would provide the nucleus from which seed stock of desirable varieties could be supplied to different interested countries. Such a central collection could also provide the necessary material for hybridisation work. It is also desirable to collect and maintain living specimens of the species of *Cocos* and study their economic possibilities both as separate species and also as parents in interspecific crosses. The following species reported to be growing wild in Brazil may, in this connection, prove useful (John and Menon, 1947).

1.	*Cocos coronata* Mart.	Extensively used for its kernel and oil.
2.	*Cocos botryophora* Mart.	Used for wood and oil.
3.	*Cocos schizophylla* Mart.	Used for the production of industrial oil and for fibre from leaves.

4. *Cocos vagans* Bondar	Used for stock fodder—oil manufacture and building construction.
5. *Cocos tostana* Bondar	Fruits have good flavour and could be used as dessert.
6. *Cocos matafome* Bondar	Produces leaf for thatching, seeds for fodder and oil. Leaves give resin.
7. *Cocos campos-portoana* Bondar	Kernels used for oil extraction.

SURVEY OF WORLD VARIETIES

There is considerable confusion at present regarding the nomenclature of varieties reported to be growing in the different coconut growing countries of the world. It might therefore be advisable to send a committee of experts to the different coconut growing areas to conduct a survey of the world varieties, and to catalogue them after the compilation of comprehensive and descriptive terminology for describing the different vegetative, flower and fruit characters of the coconut.

HYBRIDISATION

The ordinary tall variety of the coconut palm which is most commonly grown in all the coconut producing regions is highly cross fertilised in nature and is therefore heterozygous. While information on the bearing nature of the pistillate parent can be known, it is not possible to have any definite idea regarding the staminate parent, in selecting material for planting purposes. Studies on intra and inter-varietal crosses conducted in India and Ceylon have shown that it is possible to impart vigour and other desirable economic characters to the progeny. This work deserves expansion on a more generous scale since, in a crop like the coconut, the hybrids would live for over sixty years.

INTERNATIONAL SURVEY OF PESTS AND DISEASES

An international standard of classification and terminology for the pests and diseases of coconut is a long felt want. At present, a good deal of confusion exists in this respect. Either different species or genera of pests producing almost similar symptoms by their infestation of coconut palms are classified as one, or the same pest is given different names in the different areas in which coconuts are grown. For instance, the coconut beetle, *Oryctes rhinoceros* L., which is one of the most ubiquitous pests of coconuts, is known as the " Coconut rhinoceros beetle ", the " Black beetle ", the " Coconut helmet insect ", the " Palm rhinoceros beetle ", the " Asiatic rhinoceros beetle ", " Big beetle ", " Indian rhinoceros beetle ", etc. Again, infestation by other species of *Oryctes* like, *O. monoceros, O. owariensis, O. tarandu, O. cheverolati*, etc., and in some cases by other members of the same sub-family like *Strategus* sp. is now all attributed to the rhinoceros beetle.

In India, the species of palm weevil that attacks coconut is *Rhynchophorus ferrugineus* F. Other species of *Rhynchophorus* that produce similar symptoms on coconuts in other producing areas are *R. sachach* Oliv. in Malaya, Philippines and Indonesia, *R. papuanus* Kirsch. in New Guinea, *R. palmarum* L. in American tropics, *R. phoenicis* F. in Africa.

With regard to coconut diseases also the position is somewhat similar. The Bronze leaf wilt disease of coconut affords a striking example of the confusion that exists regarding correct nomenclature. What may perhaps be the same disease is known by various names at different places, e.g., "Cape St. Paul wilt " in the Gold Coast, the " Coconut Wilt Disease " in Nigeria, " West End Bud-rot " in Jamaica, and " Bronze leaf wilt " in Trinidad, Br. Guiana, etc. The " Cadang-cadang " disease of the Philippines, the " Unknown disease of coconuts " in Jamaica and the " Root (wilt) disease of Coconuts " in Travancore-Cochin (Kerala) have almost similar symptoms. The foliar symptoms exhibited by " Little Leaf Disease " in Trinidad and " Bitten-leaf " disease in Jamaica, " Frond-choke " in New Guinea are extremely similar. The possibility of a committee of experts going into this question and codifying an international standard of classification and terminology is to be considered.

STATISTICAL DATA REGARDING THE ACREAGE AND PRODUCTION OF COCONUTS

Statistical data about the acreage and production in the main coconut growing countries are in general incomplete and therefore inaccurate. This is mainly due to the fact that coconuts are more usually grown in gardens mixed with a variety of other plants. The number of trees in an acre, the proportion of bearing trees in this lot, as well as the number of nuts produced per acre in the different areas are all varying factors. Besides, there has been a lack of uniformity in the manner of collection of the data in the different producing countries, the agency responsible for compiling the reports having not stuck to any scientific principles in the collection and recording of the data. There is thus an obvious need for a new orientation and standardisation of an international procedure which would enable the accurate assessment of the total world area and production of coconuts.

PHYSIOLOGICAL PROBLEMS

The coconut has the singular feature of yielding, under suitable conditions, the valuable nuts almost at monthly intervals all through its life of about eighty years. There is thus bound to be a steady utilisation of plant food material from the soil as may be seen from the average annual removal of the main plant food ingredients in table 37. The physiological aspects of the coconut palm therefore present certain special features. A well-known factor in this connection is the long duration which is necessary for the effects of fertiliser treatments to be largely manifested on the coconut palm. There is a lag of about 2½ to 3 years which is roughly the time taken for the development of the nuts from the primordial stage to its full maturity for the fertiliser effects to become visible first and there is also a compounding advantage the fertiliser leaves on the coconut palm. The residual effects of added fertilisers last longer in coconut than in the case of ordinary perennial plants (Copeland, 1931).

Narayanan (1948) has discussed in great detail the different physiological problems of the coconut palm. He has stressed the need that exists in coconut research for a comprehensive study from various aspects such as soil chemistry, plant physiology and plant nutrition in relation to macro and micro-nutrients, as well as in the advantages of utilising recent developments in plant physiology. He has also discussed the different lines along which the numerous problems relating to the nutrition, development, yield and disease resistance could be tackled more speedily and satisfactorily, citing examples from other crop plants for each specific type of problem. It is, however, to be remembered that the growth and performance of plants in general are influenced to a great extent by the actual genetic make up of the plant, as also that soil and climatic environments interact to some extent through the change in its internal physiological processes and conditions.

The main task of the research worker in this connection involves the consideration of the different problems designed for improving the productivity of the palms, as well as dealing effectively in the prevention of loss of yield by malnutrition and pathogenic agencies. Increase in yield can be achieved as discussed earlier (Chapter X) by proper soil management, by the use of selected quality seedlings, etc., and judicious manuring. For an intelligent and efficient use of fertilisers, it is important to know the details of the soil conditions and the requirements of palms at the different stages of growth and other factors which have been already considered (Chapter IX). Till now, we have only very limited data regarding the actual nutritional requirements of the coconut palm. There is very little information especially on the micro-nutrient needs and the different interactions which the different nutrient ions undergo in the palm tissues. There is no work which has been carried out, so far, to determine the nutrient needs by plant injection methods such as those used by Roach (1947) on perennial crop plants as the apple for example. Several workers have accepted the principle, that the plant itself is the best indicator of what it can absorb from the soil and in the utilisation of available nutrients in determining the manurial needs of crops (Goodall and Gregory, 1947). There are certain well-known conditions in the coconut palm such as the nutritional foliar yellowing which is now believed to be caused by certain changes in the physical conditions in the soil as a result of water-logging and consequent anaerobic conditions. Potash deficiency in the soil is known to develop under such conditions and this has some connection with the utilisation of iron in the plant tissue which has some influence on the chlorophyl formation in plants. There are also other disorders in the palms which need the combined attention of the physiologist and the plant pathologist. The partial sterility caused by the abortion of spadices is a widespread disorder in the coconut palm and even though it is believed to be, among other factors, an after effect of drought that prevailed nearly sixteen months earlier, it is a condition which still baffles the grower. The foregoing account shows that such and allied aspects of the coconut palm are yet virgin fields for research and much work has to be carried out before we could have clear ideas of the different problems which the palm presents. It is also true that the practical difficulties in the matter of experimentation with the palms, both in pot culture as well as in the field would continue to remain and much preliminary work would have to be done to standardise accurate methods.

THE USE OF RADIOACTIVE ISOTOPES

A valuable method which may help to understand the physiological aspects of the nutrition of the coconut palm is the one which has recently become a standard method in biological studies in which radioactive isotopes are used to evaluate the requirements. Advantage is taken of the fact that the nutrient ions in fertilisers containing radioactive elements—nitrogen, potassium, phosphorus, etc.—are absorbed by the plant in the same manner as ordinary forms. By virtue of their radioactivity, their presence inside plant tissues can be traced by taking radio autographs which reveal details otherwise unobtainable regarding the rate, direction, channels of transport and storage centres of these elements within the living plant. The use of the Geiger-Muller counter helps to estimate the relative quantities of these elements. The method is simple, rapid and very sensitive (amounts as minute as 0·00015 of microgram of phosphorus having been measured). It has the added advantage over the common chemical methods in that the element added to the living system can always be distinguished from that already present in the soil. The use of the counter dispenses with the use of ordinary chemical analysis of the plant tissues for collecting the necessary data for interpretation of results. It is possible to know the quality and quantity of the fertiliser ingredient taken up by the plant from the soil in the different stages of its growth and evaluation of these nutrients required for any special purpose *in vivo* could also be carried out easily, correctly and quickly. For a perennial plant as the coconut palm, the tracer method might afford quick and accurate results on the different physiological needs. Randhawa (1956) has stressed the need for the efficient use of fertilisers by the use of radioactive isotopes as tracer elements, which have provided information on a number of points, particularly on the utilisation of fertiliser ingredients by plants. The coconut palm is an example of a plant which has shown only little response to phosphoric acid manuring. The use of P^{32} is likely to throw light on factors like the phosphorus metabolism of the palm particularly on the time at which the palm requires phosphorus, the soil depth at which the placement of phosphatic fertilisers should be done, the quantity to be applied over and above what is already present in the soil, etc. He has also discussed the use of radio-isotopes in the study of insecticide efficiency, as the tracer technique affords knowledge regarding the rate of penetration, mode of action and the site of action, etc. Sankaranarayanan (1956) has also discussed the use of P^{32} in the control of pests and diseases. The differences between the healthy and diseased tissue, can also be studied by isotope taggings. Interesting results on the physiology of host-parasite relations in the study of tobacco mosaic virus by the use of tracer techniques have been reported by Shaw and Samborski (1956). Application of the tracer technique for studying the aetiology of the important coconut diseases like the " Cadang-cadang " of the Philippines, the "Wilt (root) disease" of Travancore and the "Unknown disease" of Jamaica may provide useful information.

THE MICRO-NUTRIENT REQUIREMENTS OF THE COCONUT PALM

The present position regarding our knowledge on the micro-nutrient requirements of the coconut palm has been discussed (Chapter IX). Our information on these points is very meagre and a good deal of research work, both in the laboratory and in the field has yet to be done on these aspects. The difficulty of estimating infinitesimally small quantities of these nutrient elements impeded to a large extent the progress on these lines so far. The perfection of the techniques of estimation of very minute quantities of elements by spectrographic, photo-electric, colorimetric and chromatographic methods now render possible the accurate analysis of tissues collected from the plants in the different stages of experiments. Considerable advance has been achieved in recent years by the use of these in the understanding of several different problems. Thus, the study of photosynthesis in plants with the help of radioactive carbon dioxide the rate of movement of the soil solution, the knowledge regarding the readily exchangeable phosphates in soil and the problems of phosphorus availability, the study of the origin of parent rocks, minerals of soils and their classification, the study of translocation of nutrients and the extent to which they are taken up and utilised by plants, have made satisfactory progress. All these may help the understanding of the physiological problems of the coconut palm growing under different soil and climatic conditions. The study of soil moisture problems by neutron scattering (Van Bavel *et al.* 1956) has also been very helpful. Mulder (1948) has developed biological methods using *Aspergillus niger* for determining trace nutrients like copper. The methods are very useful in soil and plant tissue studies.

The importance and convenience of some of these methods for the determination of very minute quantities of nutritive ingredients in soil and plant tissues have been discussed by Stiles (1946). A concerted and co-ordinated use of all such available methods with due regard to the objective in view and the practical limitations in each item of study will very much help in the understanding of plant nutrition problems. Narayanan has suggested that some of these methods might be expected to be useful in diagnosing particular deficiencies of nutrient elements, e.g. potassium, calcium, magnesium, etc., in the bronze leaf wilt, or zinc in pencil point disease, etc., and serve to supplement the standard chemical methods. For a perennial palm, the early detection of a deficiency or toxic condition of any of the nutrient element and appropriate correction would go very much in improving its health and productivity. Actually, these methods are in use and Innes (1949) and Sankarasubramoney *et al.* (1951) have studied the manganese status in the coconut leaf tissue and gathered information about the role of manganese in the physiology of the palm. The latter have also reported their studies on the leaf tissue analysis of the coconut palm. Accumulation in the diseased leaf tissue of nitrogen, phosphorus and magnesium has been pointed out and the related aspects of impaired physiological activity in the leaf tissue such as the inhibition of enzyme processes or inadequate translocation of the different nutrient elements discussed. From such a study, they were also able to show the need for sampling the coconut leaf tissue for analytical work on nutrition. It was shown by them that a representative sample of the leaf in a tree with " n " number of leaves would be the one collected according to the formula $(n/2+1)$ and the leaflets between the fortieth and fiftieth on this leaf would be the typical standard. A good deal of information of a similar nature could be obtained by proceeding on similar lines.

PLANT INJECTION METHODS

The pioneering work of Roach (1938) on plant injection methods has served to enable to detect deficiencies in the plant tissue of the different nutrient elements of several fruit crops. The technique is simple, easily operated and the results quickly obtained. Thus, a deficiency of iron was detected in two days by the method of intravenal injection. Advantage could then be taken of the fact that plants are able to absorb small quantities of the nutrients in dilute aqueous solutions and assimilate them when supplied as a foliage spray. Several disorders such as manganese, copper and zinc deficiencies have been made good and normal health of plants restored. Roach (1947) has discussed these aspects with regard to detection and correction of micro-nutrient deficiencies such as manganese, zinc, etc., in potatoes.

ENZYME STUDIES

It is known that some of the trace elements form prosthetic groups of enzyme systems in plant processes such as respiration, nitrate reduction, etc. A knowledge of these enzyme reactions would be very helpful in understanding the processes of photosynthesis, translocation, etc., in the coconut palm. Our information on these points is very limited. Heinieke (1923) and Ezell and Crist (1927) have shown that catalase activity is related to growth and vigour of the plants. Sadasivan (1951) has found that the endosperm contains peroxidase, dehydrogenase, catalase, and phosphatase and has described the details of the activity of the last mentioned enzyme in the kernel. Much light could be thrown on the different aspects of nutrition of the coconut palm as well as the physiologic process *in vivo* by carrying out researches on these enzyme aspects. With regard to the important physiological processes of the coconut palm — transpiration and photosynthesis — there are only limited references in the literature. Copeland (1931) has studied the quantities of water lost from the coconut on account of transpiration and found that one pinna or leaflet loses in a day 10·8 gm of water. The estimates based on his observations vary from 28 kg to 74 kg, as the daily loss of water from a mature palm. It would be interesting to study these aspects in all their details especially when it is to be remembered that the approximate total green leaf area of a large sized coconut crown measures about 1,950 sq. metres and that the total number of stomata on the leaves of such a tree would be about 73,000 million, helping to regulate transpiration and gas exchanges of the tree. McLean (1920) working on young trees grown in shallow soil subjected to drought for several months, found that carbon assimilation was most active in the early morning. Since the coconut palm is very fastidious about its requirements of light and since there is the tendency to expose the entire crown to total sunlight availability, McLean's findings require to be reinvestigated as it would seem from the above findings that the palm is not able to utilise the full sunlight of the usual tropical day. It may be seen that these and allied aspects require careful and systematic investigation.

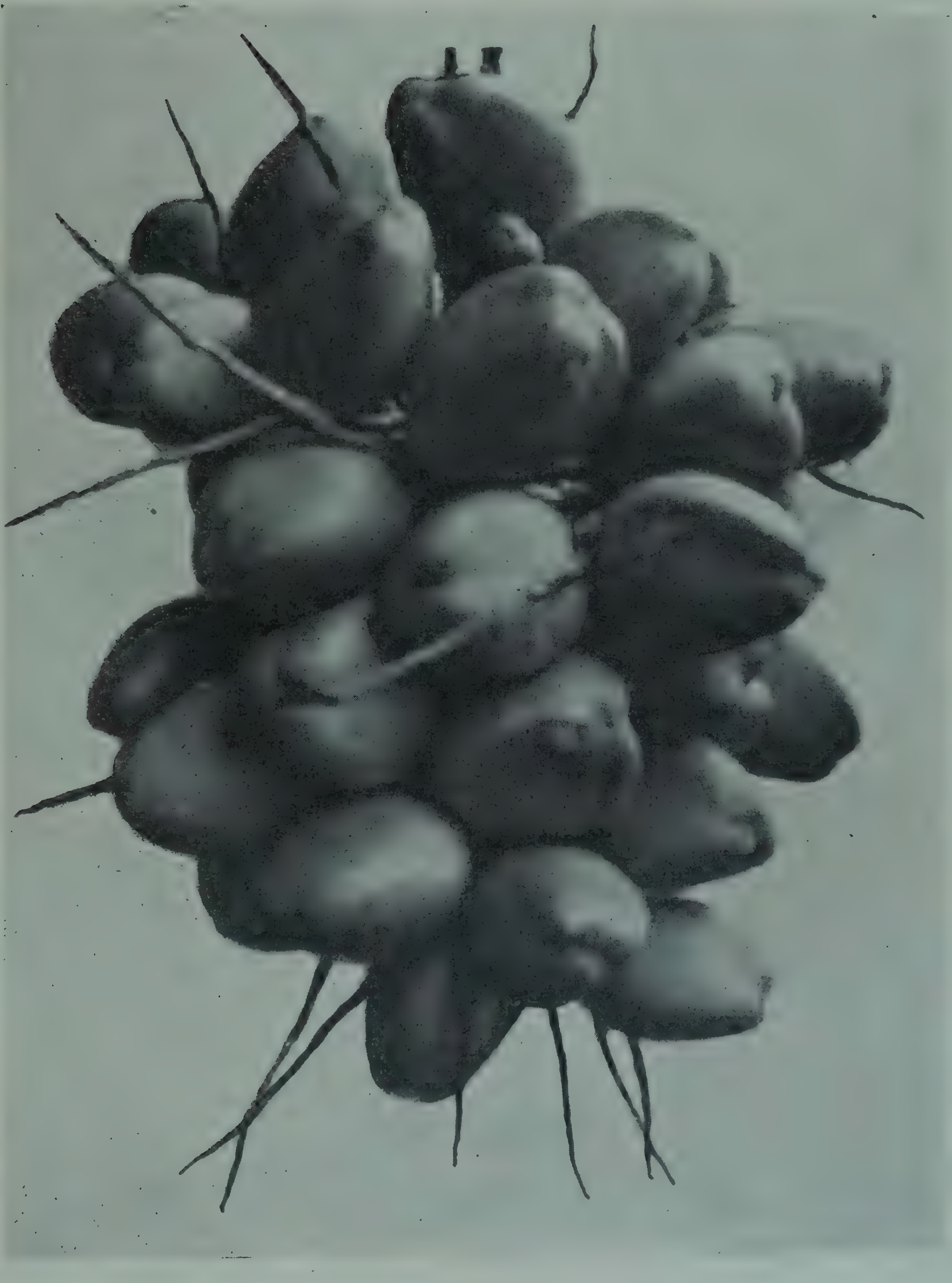

Fig. 150. A hormone-sprayed coconut bunch

Coconut milk has been described to possess growth promoting or modifying influence by Steward *et al.* (1956) probably on account of the stimulus of specific substances contained in it. Some of the growth promoting principles present in coconut milk have also been actually isolated in crystalline forms, compounds A, B, C and F by Shantz *et al.* (1952) and Steward *et al.* (1955). These authors (1955) identified compound A as 1, 3, - diphenyl urea and since then other substances, *viz.*, leuco anthocyanins, benzthiozolyloxy acetic acid (Steward) and 6, furfural amino purine (Miller *et al.* 1955) have also been discovered in coconut milk. Of these the last two are reported to be very effective in stimulating cell division and growth in plants. Probably these account for the efficient use of coconut milk in tissue culture techniques.

USE OF INDICATOR PLANTS

Briton Jones (1940), while studying the bronze leaf wilt of coconuts in Trinidad, found that practically the same symptoms of dwarfing and leaf yellowing, etc., could be induced in potted plants of the yellow stem palm (*Chrysalidocarpus lutescens*) by giving drought conditions in the pot and suggested that this can be used as an indicator plant. Wallace (1946) has discussed the uses of such indicator plants to show readily recognisable and characteristic effects by way of foliage colours and other abnormalities to detect specific nutrient deficiencies and claimed this to be a very useful method when used in combination with different fertiliser treatments. As examples of such typical indicator plants, the oat plant for manganese deficiency, sunflower for boron deficiency, potato for potash deficiency, tomato for phosphate deficiency, etc., may be mentioned. Narayanan has stressed on the limitations of these methods, particularly when some of the deficiency symptoms are likely to be masked by other interfering factors like water-logging, pests and diseases, etc. He has suggested the use of certain dwarf palms such as *Chanadera elegans* a Mexican palm which flowers when less than three feet tall, *Kentia balmorean*, *Kentia fersteriana*, *Pinanga sp. Areca concinna*, *Licuala grandis*, *Nipa fruticans* (for swampy situations) and *Phoenix zeylanica* (for drier habitats) as likely to prove useful in regard to the study of the nutrient deficiencies of the coconut palm. The green manure plant, sunn-hemp (*Crotalaria juncea*) was used as indicator plant for potassium and calcium deficiency in coconut gardens (*Annual Report*, 1956). The results obtained have been encouraging and such studies are being extended with other green manure plants such as cowpea, sunflower, etc., as suggested by Cowell (1946) to detect mineral deficiencies of coconut plantations.

USE OF HORMONES IN PLANT IMPROVEMENT

The researches of Thimman and Lane (1938) have shown that the growth and yield of agricultural crops can be improved by supplying suitable concentrations of certain growth promoting hormones to soak seeds or seedlings, when, the plants from the pre-treated seedlings grew better with increased final weights over controls. The results achieved till now are encouraging and it is worth-while to try the effects of hormones in the different phases of coconut growth. Gangolly (1953) and Gangolly *et al.* (1957) at Kasaragod have made interesting progress in the use of hormones such as 2, 4-Di-chloro-phenoxyacetic acid in the problem of shedding of buttons and incidence of barren nuts in the coconut palm. The Fig. ***150*** illustrates a hormone sprayed bunch, five months old, left unthinned with forty-three buttons developing into nuts. Details of these have been discussed in Chapter IV. Pre-treatment of seed coconuts in nutrient solutions and their subsequent growth was studied at Kasaragod (*Annual Report*, 1955). Injections into the husk of seed coconuts of nutrient solutions of ammonium sulphate, water soluble extract of super phosphate and muriate of potash singly and in combinations were found to adversely affect the germination of nuts and the growth of seedlings. The results obtained so far have not been encouraging and experiments are now under careful revision. It is however to be expected that this line of work has good possibilities in effecting plant improvement.

USE OF SOIL CONDITIONERS

Yet another item of work calculated to improve soil physical conditions and hence the health and productivity of the coconut palm consists in the use of formulations such as krilium, the alginates, etc. The use of these in several countries in different soil types and under varying conditions have proved their efficacy. The importance of suitable soil conditions in relation to the health of the coconut palm has been discussed (Chapter XIII) and it was shown that adverse soil conditions are in several instances, responsible for the disease incidence. Such coconut soils which, by virtue of their adverse physical properties promote unsatisfactory rhizosphere conditions, may probably get very much ameliorated by application of suitable soil conditioners. This field thus awaits systematic exploration.

VERNALISATION, PHOTOPERIODIC TREATMENT, ETC.

The trials to hasten flowering and fruiting by modifying environmental factors like light, temperature and moisture supply during the early stages of plant growth known as vernalisation, which have been found to be useful in case of annual plants, do not appear to have been carried out with the coconut palm. Work has also yet to be done on photoperiodic treatments which may be expected to impart some resistance to adverse conditions in the case of the coconut palm. These aspects have been considered by Narayanan who states that a proportionate effect on coconut by subjecting the seedlings to suitable periods of illumination and temperature might succeed in making the trees bear fruit earlier than they do normally. A great deal of preliminary knowledge has, however, to be secured on the photoperiodic response and other phasic behaviour of the coconut palm before this result can be achieved. The possibility of correcting defects like irregular or alternate bearing, incidence of barren nuts, abortion of spadices, etc., by artificial adjustment of the environmental conditions, nutritional levels during the vital seedling stage, etc., awaits investigation.

Sufficient emphasis has been made on the fact that the coconut palm is the victim of several pathogenic and physiogenic diseases (Chapter XII). It was also stressed that even in the case of purely pathogenic diseases like *Phytophthora* bud-rot, or the leafrot caused by *Helminthosporium halodes*, the actual curative measures when once the disease is established are often of only secondary importance, preventive measures by way of increasing the resistance of the plant to infection being very often more effective and easier. The adequate presence in the soil of all the minerals necessary for plant nutrition, their availability and normal utilisation by the plant play a very important role in the building up of disease resistance in plants. Our knowledge about the precise requirements of the nutrient elements as well as their functions and interactions in the plant tissues is still in an unsatisfactory stage and this is very much hindering progress in the different measures of disease control. Often, a disease condition may be the result of a widely disturbed plant nutrient ratio in the soil such as the one described by Hildebrand (1947). In this case, an orchard of apple trees in Texas selected for the study of internal bark necrosis, had, among others, calcium, boron and magnesium deficiency, excess of potassium and toxic levels of manganese, aluminium and iron with high soil acidity. The supply of appropriate element for specific diseases is a comprehensive problem requiring co-ordinated study by the plant physiologist, pathologist and the soil chemist.

THE USE OF ANTI-FUNGAL SUBSTANCES

In the past few years a number of compounds possessing inhibitory properties on pathogenic organisms have been reported. Lily *et al.* (1952, 1955) have observed that the crude culture extracts of *Bacillus subtilis* possess inhibitory action on some of the leaf infecting pathogens of the coconut palm such as *Helminthosporium halodes*. The elaboration of such substances with anti-fungal properties would be very useful in controlling fungal infections on the leaf tissue. This, therefore, offers a fruitful line of research which might be helpful in programmes of disease control.

OIL AND FIBRE REQUIREMENTS AND RIPENING

Another important and interesting problem in coconut research lies in the conflicting interests of the oil and coir industries. The demand of the former requires that the nuts should be fully ripe when harvested while in the latter good quality fibre could be had from husks which are just about three-fourths ripe. This again needs a fuller study for altering the ripening rates of husks and meat in order to reconcile their conflicting interest.

STUDIES ON FERTILISER PLACEMENT

Several advances recently made in fertiliser placement studies particularly by Cooke (1949) at Rothamsted have shown that definite advantages accrue by adopting special methods for manuring and fertilising the soil. The coconuts on small holdings in this country are grown in mixed gardens and the different aspects centering round the right manner of applying the fertilisers would go a long way in improving their utilisation by the coconut, increasing its yield and possibly increasing its disease resistance.

MECHANISATION

Mechanisation in coconut gardens is probably another equally important topic on which the Indian coconut grower has to bestow thought and serious attention. In land management as well as in other farming operations, mechanisation has recently greatly increased efficiency. The progress in different countries is to some extent indicated by the increase in the average number of acres under crops per farm worker in different years. In India, where coconut cultivation is mostly in small holdings, mechanisation might take a long time before it becomes routine in the schedule of farm operations. Wijewardene (1953) details the different aspects of mechanisation on coconut estates in Ceylon.

The foregoing account makes it clear that there are several items on which concerted, co-ordinated and systematic research work has to be carried out with a view to bring coconut cultivation on a sound and economic basis. It is seen that quite an array of diverse problems present themselves in this connection which require patient and careful study. There is no doubt that any attention paid to the coconut palm will be adequately rewarded as has been the experience of coconut growers in all parts of the coconut growing countries.

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